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Papers

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Journal of the
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HIGH-PRESSURE STEAM MAIN UNDER NEW YORK CITY STREETS[1]

James C. Fisher,[2] A.M. ASCE
(Proc. Paper 1279)

SYNOPSIS

This paper treats of the design and construction of a 24" steam main to operate at 400 psig for underground installation in New York City streets. To the best of the authors knowledge it is the first steam main of this size and pressure rating which has been built for general steam distribution purposes in the city. Certain design features new to the company's steam main construction practice were introduced in this project and are described herein.

INTRODUCTION

The Consolidated Edison Company of N.Y. is a public utility corporation engaged in the business of furnishing the population of the metropolitan area of New York City with electric, gas and steam service. The steam business is confined to the mid-town and the financial sections of the borough of Manhattan. Steam is obtained from either Company owned steam generating plants or as a by-product of the electric generating plants. This paper is concerned with a project recently completed by the Company in connection with its steam distribution system.

There has been a decided increase in the demand for steam service in recent years. This up swing in the steam business is partially due to the trend towards centralized air conditioning in office buildings, hotels and new apartment houses. While the Company's existing facilities are adequate to satisfy all of its present steam customers it was felt that with the rapid increase in the demand for steam supply and the forecast of future requirements, the present facilities should be expanded. The Company's forecast

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analysis indicated that the most likely need for additional steam service would be in the financial district of down-town Manhattan. The Company has a steam generating station in this area known as the Burling Slip Station. The location of this station is shown on the attached map Figure 1. It was initially considered to expand the generating facilities of this station to meet the prospective increase in steam business. Economic and engineering studies which were made of this proposal however indicated that the cost of remodeling this station to increase its capacity would be extremely high. In addition there would be operating problems that might be difficult to overcome. An alternate to this proposal was to bring steam from some other source to the Burling Slip Station from whence it could be distributed throughout the lower Manhattan area. Steam could be readily made available for this purpose at the Company's East River electric generating station located at the foot of 14th Street and East River Manhattan. Reference to Figure 1 shows the geographic relationship between the East River and Burling Slip stations. The stations are approximately 2-1/2 miles apart. While it was recognized that the construction of a pipe line of sufficient capacity to transfer the required amount of steam between these two stations would be a project of considerable magnitude, it was the opinion of the Company that the installation of this facility would be preferable to increasing the steam generating capacity of the Burling Slip station. Based on this decision the engineering department of the company was authorized to prepare plans and specifications for a high pressure steam main to be laid from the East River Station to the Burling Slip station. This main would deliver sufficient steam to satisfy the immediate and anticipated demand at Burling Slip. The sales and engineering departments of the Company estimated this demand to be 1,000,000 lbs. of steam per hour for delivery to Burling Slip at 175 psig. It was calculated that a 24" main operating at 400 psig would meet these requirements. The selection of this particular pipe size and operating pressure was considered to be the optimum within the limits of practical and safe operations.

Planning the Route

Planning the route for the steam main between the terminal point at East River Station and Burling Slip was the next step in the engineering study. Some idea of the problem of finding space below the City's street surfaces for a pipe line of this size with its necessary appurtenances may be obtained from the following statistics on subsurface structures. Subsequent to 1884 when the New York State legislature made it mandatory for all utility lines to be laid under the streets the number of these structures has increased to the figures shown in the tabulation Figure 2. These figures do not include the rapid transit subway structures, The New York Central's underground trackage for practically the full length of Park Avenue, other railroads with trackage below the street surface, vehicular under-passes, private and publicly owned vault space beneath the sidewalks, pneumatic mail tubes and numerous other buried facilities which made the installation of additional buried lines a formidable task. It may be recalled from the steam main distribution map Figure 1 that the nearest straight line route with minimum changes in direction between the East River Station at 14th Street and the Burling Slip station at Pearl Street would follow Second and Third Avenues. The selection of a route along

these streets however would mean a long cross-town-run upon leaving the East River Station and would involve crossings at several busy and congested intersections and in addition would bring the main into the area of future rapid transit subway construction. A study of street traffic and subsurface conditions along the streets to the east of these main thoroughfares indicated that a route along Avenue D—Henry Street and thence Pearl Street appeared more favorable. Layout plans were made for the installation of the steam main along this route. The length of the steam main run along this route would be 14,000 feet. The layout plans consisted of a complete set of topographical drawings for the entire route. The drawings were made to a scale of 1" = 20'. They show all surface features as well as all subsurface structures which might interfere with the installation of the steam main. The data used in the preparation of these layout plans were obtained from several sources. An over ground survey was made and plotted. This plot was checked against the City's topographical maps to confirm building lines, street lines and grades etc. Subsurface data on the location of sewers, watermains, rapid transit subways and other City owned underground structures were compiled from City records. The location of other utilities in the streets such as telephone and electric conduit gas mains, etc., were obtained from the owning company's records. The location of these underground structures and utilities as obtained from records was confirmed by overground pipe locator survey. Test pits were dug at street intersections where congested and complicated subsurface construction required a detailed study to determine whether space could be found for the installation of the steam main.

There are special construction items required in the case of a high pressure steam pipe line that are not ordinarily provided for in water or gas pipe line construction. Such special construction includes provisions for pipe expansion, intermediate anchors, thrust anchors, valve and drain manholes. A steam main must be provided with an insulated coating to minimize heat losses and most thermal insulating materials require both waterproof and mechanical protection. This in turn means some sort of housing or enclosure structure. This type of construction required careful consideration of subsurface conditions to find available space and avoid as much as possible interference with existing structures. The design of these special items of construction will be discussed in more detail later on in this paper.

In selecting the lane for the steam main the objective was to maintain as straight a pipe run as possible. When ever a change in the direction of the pipe line in excess of 45^0 becomes necessary, a thrust anchor was required. Thrust anchors were also required at each valve manhole location. These thrust anchors were of heavy construction and soil data investigations were made at each location where the thrust anchors were located. The soil data were obtained from borings and test pits. It was interesting to note that our subsoil studies confirmed to a reasonable degree the data shown on the New York City Viele map. This map was made in 1865 in connection with a sanitary survey of the City. It shows original shore lines, made lands and the location of old stream beds long since filled in or diverted. It is most useful in the investigation for foundations, etc. Light load anchors were also required for expansion joint thrusts. It was possible to build those anchors however, into the base of the steam main housing and external construction was not necessary.

All of these special construction items together with the steam main and

its enclosure were plotted in both plan and profile on the layout drawings. Stationing and base line references were indicated so that the line of the steam main could be established on the ground for construction. The finished construction layout drawings together with complete job specifications and detail drawings for the various special construction items were furnished the Company's Outside Plant Construction department. The construction department proceeded with the preparation of construction cost estimates, filing of the necessary drawings and data with the New York City authorities for permits to install the steam main in the City streets and finally the awarding of contracts for the various items of construction work. Most of the materials required for the project such as the pipe, valves, fittings, expansion joints, precast concrete manholes, etc., were purchased by the Company on individual Company standard specifications.

In addition to the preparation of the construction layout drawings, design and detail drawings for the special construction items such as the enclosure for the steam main, provision for expansion and the methods of anchorage were prepared and issued.

Included with and made a part of the working drawings was the job specification. This specification is listed under the Company's Construction Standards as "Specification for the Construction of a Steam Main to Operate at 400 PSI and 500^0 F." The specification treats in detail only the items of work pertinent to this job. These would be in the category of trenching, installation of the steam main, inspection, testing, etc. Items of material, appurtenant structures, etc., are all covered by either specific Company specifications or appropriate national specifications and standards. These supplementary specifications are referred to but not necessarily included in the job specification. It has been the experience of the company that specifications condensed in this form furnish the construction forces with all data required for the pertinent work of the particular project. In this manner the disadvantages for on the job use of the conventional cumbersome and voluminous specifications which cover in detail all materials and appurtenances are avoided. It should be understood however that all supplementary specifications are a part of and as binding as though written out in the job specification.

Pipe and Fittings

Since the project involves the installation of a steam main, the pipe to carry the steam was one of the first items to consider in the design. It was stated in the beginning of the paper that a 24 inch diameter pipe would be required for the specified quantity of steam to be delivered from East River Station to Burling Slip station. With the pipe size given, it became a matter to decide upon material, wall thickness and method of jointing. The criteria which were used as a guide in these determinations was the "American Standards Association Code for Pressure Piping B 31.1-1955 Section 4 District Heating Piping Systems."

A carbon steel of soft weldable quality Grade B, with a carbon limitation of 0.30% was selected as the material for the pipe. The manufacture of the pipe was specified to be ASTM A-53 Grade "B" Seamless. The pipe was ordered in double random lengths of 40 feet. Butt weld joints made in accordance with the ASA Standard for weld ends was specified. These requirements were based on long experience on the part of the company with steel

pipe for high pressure gas mains where jointing was done by field welding. It was found that mild carbon steel pipe whether Grade A or Grade B with a carbon limitation of 0.30% satisfactorily meets these requirements. Aside from the technical and construction advantages it has also been the Company's experience that carbon steel pipe is usually readily obtainable. Internal pipe wall stresses with the pipe operating under a pressure rating of 400 psig at 500° F were computed. Localized shear stress at points of anchor attachment were checked for critical values. The longitudinal pressure stresses and hoop stresses due to internal pressure and the bending stresses caused by expansion thrust at bends were combined in accordance with the theory of principal stresses and compared with the allowable combined stress as specified by the ASA Code for Pressure Piping. The stress analysis indicated a wall thickness of 1/2" would be required. Stresses resulting from vehicular and early pressure loads were not considered in the determination of the steam main wall thickness since the entire pipe line would be installed within a self-supporting enclosure.

The matter of providing for expansion and anchorage of the steam main presented a special problem. Since the entire line would be buried below paved city streets and therefore not readily accessible for either maintenance or inspection, reliability was of prime importance. The company's experience with existing underground steam lines operating under similar service conditions favored the element or bellows type expansion joint. A company specification was written to cover the manufacture of an expansion joint which would perform satisfactorily under the conditions stipulated above. A few of the important items incorporated in this specification are enumerated below:

All joints were to be 24" steel pipe size.

The joints were specified for use in high pressure steam mains operating at 400 psig maximum pressure and 500°F maximum temperature.

The joints were to be either hydraulically formed or of the welded disc type. Elements were specified to be stainless steel type 347 or type 321 and were to be made from formed plate.

External rings were optional. This stipulation was made to provide a broader field of suppliers for this type of equipment.

The ends of the expansion joints were to be fabricated for welded connections.

Two traverse ranges were specified, a single unit to permit a 5" traverse and a double unit to permit a 10" traverse. All joints were to be subjected to a hydrostatic test of 600 psig.

A spacing of 250' for intermediate anchors was established as the maximum safe distance to insure against excessive stress in the pipe which might induce buckling or misalignment. Double expansion joints (10" traverse) were located approximately midway between the intermediate anchors. For practical purposes anchors were placed at or close to street intersections. This permits future connections to the steam main at fixed points. The intermediate anchors were of comparatively light construction since they were only required to provide sufficient stability to withstand the force necessary to compress the expansion joint its full rated movement. This force where stainless steel elements were used was computed to be 7000 pounds. Figure 3 is a view of the expansion joint and intermediate anchor.

Anchorage

It was previously stated that thrust anchors would be required at all main line valves and at bends where changes in direction would exceed approximately 45^0. These anchors would be subjected to thrust loads of approximately 300 kips. A considerable amount of study was devoted to this problem. Pile foundations were initially considered for these anchors. Investigations by Dr. Terzaghi ASCE and Mr. A. E. Cummings ASCE pertaining to the stability of pile foundations subjected to lateral thrusts were used as a basis for the design of a suitable pile foundation. The area required for a pile foundation to satisfy this design presented a serious space problem. It can readily be appreciated that the construction of pile group foundations in the congested city streets through which the steam main was laid would have been a very costly operation. In view of this objection the possibility of using a slab footing for anchorage was investigated. Considering that the steam main was a continuous structure and in practically all instances there were reasonably long straight runs on either side of anchor locations, it was decided that slab footings would be quite adaptable for this purpose. The design of a slab anchor footing was prepared and adopted for the project. The details of this footing are shown in Figure 4. The stability of this footing to resist thrust depends on frictional resistance to movement of the base of the slab augmented by keys or toes to develop lateral earth resistance. The structural steel WF grillage beams are continuous for the full length of the slab footing. A structural steel welded attachment was made between the grillage beams and the steam main at anchorage points. Near the north end of the project unstable soil resembling quick sand or bulls liver was encountered at subgrade. This soil was not suitable for frictional anchorage resistance. Structural steel H piles were driven at the toe locations and these piles were welded to the slab grillage members. It can thus be seen that the slab anchor could be adopted to most any soil condition. Further the slab anchor offered the advantage that it could be constructed entirely within the trench lines for the steam main and in addition it would be used at all locations where anchorage would be required.

Insulation

Mention was previously made of the importance of preventing heat losses from the main. This was accomplished by encasing the main for the entire length of the run with a thermal insulating covering. Several materials were investigated and tested with the idea of finding a material which would serve both as an insulator and a protective water-proof coating for the steam pipe. While a few materials appeared promising it was decided for reasons stated later in this paper that the insulated coated steam pipe should be housed in an independent structure. The limited area which was available for the installation of the steam main in the City streets made it imperative that the insulation occupy the minimum space consistent with thermal efficiency. This investigation convinced the Company that its present standard asbestos block type insulation for underground steam mains was best suited for this particular installation. Accordingly a Company standard Specification EO-9004 for Thermal Insulation of Underground Steam mains for temperature up to 750^0F was issued for this installation. The type of insulation referred

to in the specification for this steam main was a fibrous solid type asbestos insulation which would conform with Type IV of Federal Specification HH-1-561C "Insulation, Thermal Asbestos, Block and Pipe Covering (for temperatures up to 750°F)." The insulation was applied to the pipe in full round sections of single thickness 4" in depth. Full round sections were used where ever possible. Matched half round sections were used only when required. Block insulation was used for fittings, valves, expansion joints, etc.

Prefabricated Construction

It was previously stated that the insulated coated steam pipe would be housed in an independent structure. This housing or casing structure was intended to function as follows. First it would provide protection for the insulated coated steam pipe against the effects of heavy street traffic loads, open excavations, washouts, etc. Second it would permit the traverse of the steam main to take place without abrasive damage to the insulation. Third it would provide water-proof construction which is necessary for the efficiency of the insulation. In addition to the above there was the further stipulation that the housing or casing structure be a prefabricated unit containing the assembled steam pipe with its insulated coating and ready for immediate placement in the trench upon arrival at the job site. This arrangement minimized as much as possible disruption of vehicular traffic and inconvenience to the general public. This is a most important consideration where the work must be carried on in congested city streets.

Several designs of prefabricated sectionalized steam main structures were developed and their economic and construction features compared. Two of these designs were adopted for the project and detail drawings were prepared for their fabrication and installation. Both designs had the following features in common. They could be built and handled in 40 ft. lengths and they included a self supporting enclosure shell to encompass the insulated coated steam pipe. The enclosure shells were designed to carry the following loadings:

a) A live load consisting of a 20,800 lb. vehicular wheel load applied at the street surface. This load intensity was derived from the American Association of State Highway Officials H-20 loading augmented by an impact factor of 30%.
b) Effects of earth pressures and superimposed static loads, weight of earth cover, subsurface structures, etc., for trench depths ranging from 5 ft. to 11 ft. Based on the above load intensities wall stresses in the enclosure shells were determined employing the theory developed by Dean Anson Marston Hon. M. ASCE and Professor M. G. Spangler, M. ASCE for evaluating the supporting strength of underground conduits. A limiting stress which would result from a vertical deformation of one inch on a right section of the shell enclosure was used to determine the shell wall thickness. Flexure or beam stresses which might result from bending along the longitudinal axis were also investigated since the prefabricated steel sections of the composite steam main structure would be made up in 40 ft. sections and handled in these lengths.

Figure 5 shows a typical 40 ft completed section of the prefabricated 24" steam main with 36" x 1/2" steel pipe shell construction. The completed

section weighs approximately 7 tons. It may be seen from the figure that the steam pipe is supported within the circular pipe shell enclosure on cast iron roller supports and is independent of and free to move within the enclosure. With the exception of a few special joints which will be discussed under corrosion protection all joints on the steam pipe were welded. The preparation of the pipe ends and the welding was specified to conform with the Company's standard welding specification. All welded joints on the 24" steam main were subject to radiographic examination using X-ray method and qualified in accordance with a standard Company procedure. Longitudinal expansion of the steel shell enclosure was provided for by the installation of a compression type mechanical couplings. These coupling joints were spaced at 125 ft. intervals. "Dresser" couplings were used for this purpose on this installation. Intermediate joints were of the weld over sleeve type. Figure 8 shows the methods used in jointing the steam pipe and the shell enclosures.

The alternate prefabricated design which was used on the project is shown in Figure 6. This design was similar to the design described in the previous paragraph with the exception of the enclosure shell. In this design the shell consisted of a 36" I.D. corrugated #16 gauge metal culvert, with an exterior coating of concrete 4" thick. A 40 ft. completed section conforming with this design weighed approximately 14 tons. An interesting feature of this design was the use of prestress longitudinal reinforcement in the concrete coating. This idea was proposed by the manufacturer of the concrete coated prefabricated sections as a means of stiffening these 40 foot sections to prevent cracking of the concrete coating during handling and installation.

The joints for the steam pipe in this design were welded similar to the previously described design for the steel shell construction. The joints for the concrete coated corrugated pipe shell consisted of a special field poured concrete sleeve. Circular rubber gaskets at the ends of the concrete coating and shielding material around the protruding ends of the corrugated metal pipe prevented bonding with the field poured concrete sleeve and permitted free longitudinal expansion movement of the concrete coated corrugated metal shell.

It was planned to use prefabricated construction for the major portion of the installation. The steel shell type of construction was intended for use at the north and south ends of the project where it was expected tide water would be encountered. The concrete coated corrugated metal pipe type of enclosure was laid out for the intermediate high ground areas. It was anticipated in the planning of the route for the steam main that there would be locations particularly at street intersections where the installation of the prefabricated sections would not be practical. The layout for the steam main at these locations called for short sections of pipe, bends, offsets, etc., in order to pass beneath or over the numerous other subsurface structures in its path. It was necessary where this type of construction was required to enclose the main in a field poured concrete box type structure. The design for this type of enclosure was prepared to conform with conventional reinforced concrete design practice for rectangular or square cross section culverts. Figure 7 is a typical detail of the field fabrication and box type concrete enclosure.

Manhole and Chambers

Along the line of the steam main there were 7 main valves approximately 2,000 ft. apart. Each of these main valves was housed in an underground

manhole. These valve manholes were built on an anchored base. Wherever possible precast concrete construction was used for these manholes. The present concrete manhole design used for the valve manholes was developed by the Company several years ago for use on its electrical distribution system. The design provides for 3 component units which upon assembly make up a complete reinforced concrete manhole. These units are, a roof slab, floor slab and a continuous four wall cell. The cell was designed in accordance with the principles of continuity or fixed end moments. These cells are capable of withstanding lateral earth pressures and H-20 highway loads without support from either the roof or floor slabs. Figure 9 shows the details of a precast concrete valve manhole. In addition to the valve manholes, trap manholes were installed at all low points along the steam main. Condensate from the steam pipe was collected in these trap manholes and by means of special equipment was either drained or pumped to a sewer depending upon the relationship of the flow line of the sewer to the depth of the trap. Figure 10 shows the method of collecting the condensate and drain to sewer. There were 13 of these chambers along the line of the steam main. At 11 locations where the flow line of the steam main was below the sewer flow line it was necessary to install an additional manhole to house pumping equipment to eject the condensate to the cooling chamber and thence to the sewer.

Cathodic Protection

It is the practice of the Company to provide cathodic protection for all steel pipe lines laid in soils where corrosion trouble is anticipated. Extensive soil surveys and records of corrosion experience with its existing facilities have made it possible for the Company to predict quite accurately the necessity for cathodic protection at any location within its territory. The section of the city through which this steam main was to be laid was an area where cathodic protection would be required. The Company's standard for cathodic protection for steel gas mains specify an bitumastic enamel coating and wrapping process. In the case of the steam main cathodic protection was specified for the steel shell casing pipe and all steel encased couplings expansion joints, etc., where they would come in contact with the earth or backfill. A special specification was prepared for the high pressure steam main installation. This specification designated as specification EO-9005 while providing for the standard method of coating and wrapping was modified to include coating materials which would withstand the higher pipe surface temperatures than ordinarily encountered in gas mains. As a further means of protection the 24" steam pipe through long runs of the steel shell casing was isolated electrically by the insertion of flanged insulating joints at approximately 3000 ft. intervals. Flanged insulating joints were also inserted in the 24" steam pipe where sections of the prefabricated steel shell casing joined with sections of the prefabricated concrete covered corrugated metal pipe casing. Magnesium anodes were installed where specified on the layout drawings usually at manholes or anchor locations where structural steel members might come in direct contact with the earth.

Inspection and Tests

In general the inspection of all construction in connection with the installation of the 24" high pressure steam main was made by personnel of the

Company's Outside Plant Construction Department. Mill inspection of the pipe, expansion joints, valves and special fittings was conducted by both a nationally recognized inspection service retained by the Company and the Company's purchasing department inspection organization. All welded joints on the 24" steam pipe were examined by X-ray method. An industrial radiographic inspection company which specializes in this service was retained by the Company for this purpose.

The testing of materials where required in the job specification EO-9003 was done by the Company's test bureau. These tests included electrical tests of the pipe coating in connection with cathodic protection, testing of concrete cylinders, testing of welder's qualification specimens, etc. All tests with the exception of tests made on the site were done in the Company's testing laboratory. Prior to being placed in operation the entire line was subjected to a steam pressure test equivalent to the maximum operating pressure of 400 psig. The test pressure was held until a complete survey of the line had been made to check for leaks, operation of the expansion joints, stability of anchorages and to insure the proper operation of all appurtenances.

Construction

Two general contracts with separate contractors were let on a unit price basis for the trenching, installation of the steam main and field poured concrete work. The welded jointing of the 24" steam pipe was sublet by both of the general contractors to a specialized pipe line welding company approved by the Company. All welders used on the work were qualified in accordance with the Company's procedure for the qualification of welders. All pipe materials, valves, expansion joints, forged fittings, etc., were purchased by the Company and delivered to the construction contractors at the job site. Separate contracts were placed by the company for the assembly and delivery to the job site of the prefabricated steam main sections.

The work was carried on in three sections and executed in a manner to cause the least inconvenience to the general public as possible. Considering the narrow downtown Manhattan streets and the confined working areas with little or no space for the storage of materials, this was a formidable task in itself.

Some trouble was experienced at both the north and south ends of the job with poor soil conditions. A large part of this area was reclaimed land and every conceivable type of material had been used as fill over the years. The elevation of the surface terrain was quite low and the subgrade of the steam main trench was at or below tide water level for long stretches. Modification of the grade of the flow line of the steam main to avoid these low areas was not always possible since the proper pitch of the main for drainage had to be considered and in addition raising the main introduced serious complications with other subsurface structures. Some attempt was made to consolidate and drain the trench but here again the lack of working space presented difficulties. Dependence was placed on tight sheathing and constant pumping. A reasonably dry trench was a necessity to insure water tightness of the joints and avoidance of seepage into the thermal insulation around the steam pipe. In the vicinity of 10th to 12th Streets near the north end of the project a fine water suspended silt condition was encountered and presented quite a problem for anchorage construction. It was at this location that the steel pile anchors

previously mentioned in the section on anchorage were used. The piles were driven to 30 and 40 ft. depths below subgrade where a firm bearing stratum was encountered.

By far however the most costly and difficult problems was interference with other subsurface structures. While many of these interferences were anticipated and provided for on the layout and construction drawings, others because of the lack of records or the inaccuracy of the records available were encountered during the construction operations. The Company's outside plant construction department realizing these probable interference problems started the work at street intersections as one of the first operations. It was at such locations where most of the rebuilding of existing subsurface structures to clear the route for the steam main would be expected. This work involved considerable relaying of existing water and gas mains, underground electric and telephone lines, modification of sewers, etc., all expensive and time consuming operations.

The construction of the 24" high pressure steam main was under the direct supervision of the Company's outside plant construction department. Experienced construction supervisory personnel of this department were assigned to the work at all times and supervised all of the contractor's and sub-contractor's operations. Representatives of the Company's engineering department were also assigned directly to the construction work and were available for consultation and field engineering work. All survey work of providing the contractor with lines and grades, obtaining accurate as constructed locations of the main as laid and the location of its important appurtenances was done by the Company's survey section.

Construction for the 24" high pressure steam main was started in March of 1955 and completed in May 1956. The total cost of the installation was approximately $3,000,000 or on a unit basis the cost was about $244. per linear foot of main.

A summary of the principal items of construction were as follows:

Length of steam main with steel shell casing	5,000 Ft.
Length of steam main with concrete casing	8,350 Ft.
Number of Expansion Joints	59
Number of Valve Manholes	7
Number of Drain Manholes	13
Number of Pump Manholes	11

As of the date of this paper the main is in full operation and delivering steam to the areas required.


CONSOLIDATED EDISON CO. OF NEW YORK INC.
STEAM DISTRIBUTION SYSTEM

FIG. 1

PIPES - CONDUITS AND UTILITY LINES UNDER NEW YORK CITY STREETS

MANHOLES	683,000
TELEPHONE WIRES	15.5 MILLION MILES
ELECTRICAL DUCTS	19,800 MILES
GAS MAINS	7,000 MILES
WATER MAINS	5,500 MILES
SEWERS	5,000 MILES
TELEVISION CIRCUITS	2,200 MILES
STEAM MAINS	87 MILES

FIG. 2

AS OF AUGUST 1956

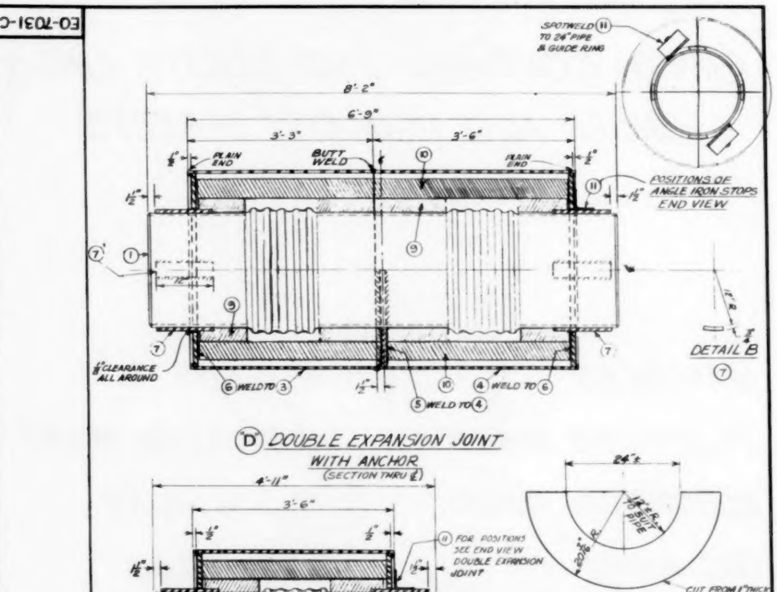
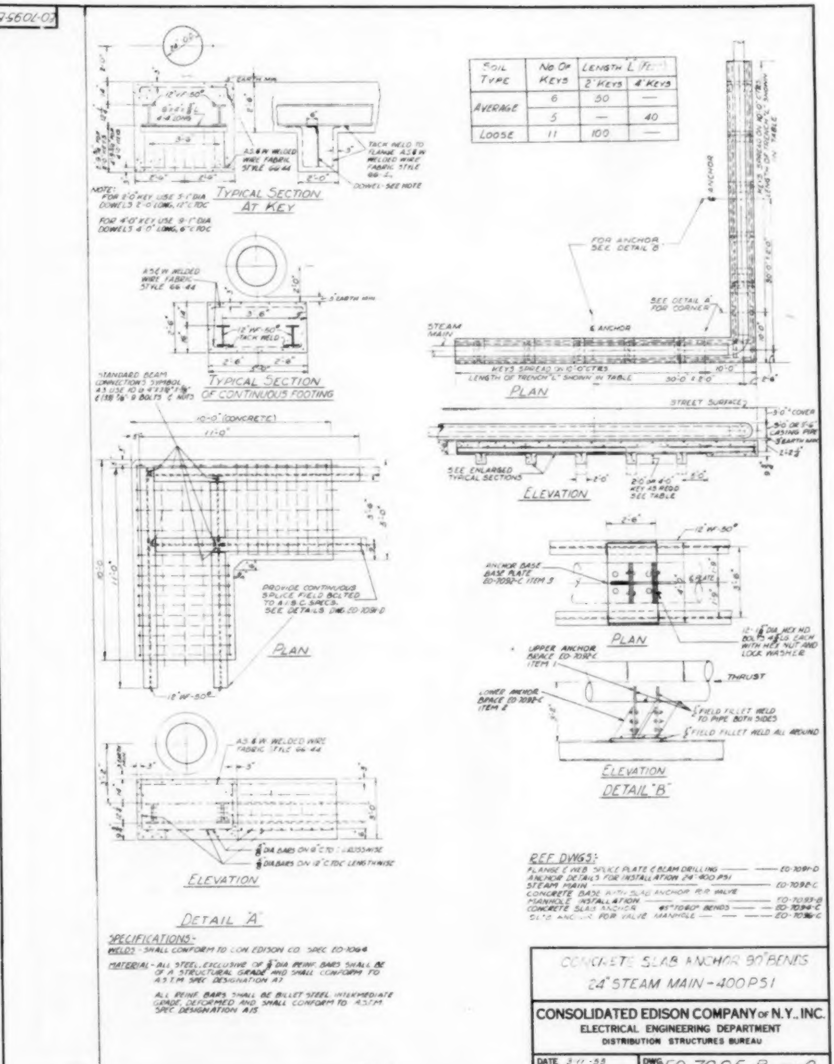

EO-7031-C
SPOTWELD (11) TO 24" PIPE & GUIDE RING
POSITIONS OF ANGLE IRON STOPS END VIEW
8'-2"
6'-9"
3'-3"
3'-6"
PLAIN END
BUTT WELD
1/8" CLEARANCE ALL AROUND
(6) WELD TO (3)
(5) WELD TO (4)
(4) WELD TO (6)
DETAIL B (7)
"D" DOUBLE EXPANSION JOINT WITH ANCHOR (SECTION THRU ℄)
4'-11"
(11) FOR POSITIONS SEE END VIEW DOUBLE EXPANSION JOINT
24"±
CUT FROM 1" THICK STEEL PLATE
DETAIL A (5)
PLAIN ENDS
(6) WELD TO (8)
"S" SINGLE EXPANSION JOINT (SECTION THRU ℄)
NOTES.-
ALL RESTRAINING DEVICES FURNISHED WITH EXPANSION JOINTS FOR RIGIDITY DURING SHIPMENT SHALL BE REMOVED BY ENCLOSURE FABRICATOR.
MATERIAL FOR PLATES & RINGS SHALL BE OF STRUCTURAL GRADE & SHALL CONFORM TO ASTM SPEC. DESIGNATION A7
ALL WELDS ON ENCLOSURE AROUND EXPANSION JOINTS SHALL BE 1/2" FILLET WELD EXCEPT WHERE NOTED.
ALL WELDS SHALL CONFORM TO CON.ED.CO. SPEC. EO-1064
THE SECTIONS OF UNIBESTOS INSULATION SHALL BE TIGHTLY BUTTED AND JOINTS WRAPPED WITH ONE LAYER OF ASBESTOS TAPE. SPLIT SECTIONS SHALL BE BANDED IN PLACE WITH STAINLESS STEEL BANDS (2) & CLIPS.
AFTER FABRICATION THE EXTERIOR OF THE 42" ϕ PIPE SHALL BE COATED IN ACCORDANCE WITH CON. ED. CO. SPEC. EO-9005.
THE EXPOSED COATING SHALL BE COVERED WITH ROCKSHIELD PROTECTION IN ACCORDANCE WITH CON. EDISON CO. SPEC. EO-8063.
ITEM 5 & ITEM 7 SHALL BE FURNISHED WELDED TO EXPANSION JOINT BY EXPANSION JOINT VENDER.
VENDER OF FABRICATION ENCLOSURE SHALL INDICATE DIRECTION OF FLOW ON EXTERIOR OF ENCLOSURE OF EXP. JOINT.
BILL OF MATERIAL
ITEM NO. | QUAN. "D" | QUAN. "S" | DESCRIPTION
1 | 1 | | 24" ϕ DOUBLE EXPANSION JOINT, AS PER CON. EDISON CO. SPEC. EO-9002
2 | | 1 | 24 ϕ SINGLE EXPANSION JOINT, AS PER CON. EDISON CO. SPEC. EO-9002
3 | 1 | | 42" ϕ STL. PIPE 1/2" WALL, 3'-3" LONG, AS PER CON. EDISON CO. SPEC. EO-1055
4 | 1 | | 42" ϕ STL. PIPE 1/2" WALL 3'-6" LONG, AS PER CON. EDISON CO. SPEC. EO-1055
5 | 1 | | STEEL ANCHOR PLATE AS PER DETAIL A
6 | 2 | 2 | STEEL RING 25 1/4" I.D. x 40 1/2" O.D. x 1" THICK
7 | 8 | 8 | BENT STEEL PLATES 12" LONG x 3" WIDE x 1/2" THICK, SEE DETAIL B
8 | | 1 | 42" ϕ STL. PIPE 1/2" WALL, 3'-6" LONG, AS PER CON. EDISON SPEC. EO-1055
9 | AS REQD | AS REQD | UNIBESTOS BLOCK INSULATION, 24" I.D. x 30" O.D. AS PER CON. ED. CO. SPEC. EO-9004
10 | AS REQD | AS REQD | UNIBESTOS INSULATION, 30" I.D. x 38" O.D. AS PER CON. ED. CO. SPEC. EO-9004
11 | 4 | 4 | 4" x 4" x 1/2" ANGLE IRON STOPS 8" LONG (2 AT EACH END OF ASSEMBLY)
FABRICATION OF ENCLOSURE FOR EXPANSION JOINTS
24" STEAM MAIN 400 P.S.I., 500°F.
CONSOLIDATED EDISON COMPANY OF N. Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU
DATE 1-27-55
LAST REV. 3-12-55
DWG. NO. EO-7031-C REV. 3

FIG. 3


EO-7095-B
TYPICAL SECTION AT KEY
NOTE: FOR 2'-0" KEY USE 5-1" DIA DOWELS 2'-0" LONG, 12" C TO C
FOR 4'-0" KEY USE 9-1" DIA DOWELS 4'-0" LONG, 6" C TO C
TYPICAL SECTION OF CONTINUOUS FOOTING
PLAN
ELEVATION
DETAIL "A"
SOIL TYPE | NO. OF KEYS | LENGTH "L" (FEET) 2' KEYS | 4' KEYS
AVERAGE | 6 | 50 | —
AVERAGE | 5 | — | 40
LOOSE | 11 | 100 | —
STEAM MAIN
KEYS SPREAD ON 10'-0" CTRS
LENGTH OF TRENCH "L" SHOWN IN TABLE
FOR ANCHOR SEE DETAIL "B"
SEE DETAIL "A" FOR CORNER
STREET SURFACE
SEE ENLARGED TYPICAL SECTIONS
2'-0" OR 4'-0" KEY AS REQD SEE TABLE
ANCHOR BASE BASE PLATE EO-7092-C ITEM 3
UPPER ANCHOR BRACE EO-7092-C ITEM 1
LOWER ANCHOR BRACE EO-7092-C ITEM 2
THRUST
ELEVATION
DETAIL "B"
PROVIDE CONTINUOUS SPLICE FIELD BOLTED TO A.I.S.C. SPECS. SEE DETAILS DWG EO-7091-D
REF DWGS:-
FLANGE & WEB SPLICE PLATE & BEAM DRILLING — EO-7091-D
ANCHOR DETAILS FOR INSTALLATION 24" 400 PSI STEAM MAIN — EO-7092-C
CONCRETE BASE WITH SLAB ANCHOR FOR VALVE MANHOLE INSTALLATION — EO-7093-B
CONCRETE SLAB ANCHOR 45° TO 60° BENDS — EO-7094-C
SLAB ANCHOR FOR VALVE MANHOLE — EO-7096-C
SPECIFICATIONS-
WELDS - SHALL CONFORM TO CON. EDISON CO. SPEC EO-1064
MATERIAL - ALL STEEL, EXCLUSIVE OF 5/8" DIA REINF. BARS SHALL BE OF A STRUCTURAL GRADE AND SHALL CONFORM TO A.S.T.M. SPEC DESIGNATION A7
ALL REINF BARS SHALL BE BILLET STEEL, INTERMEDIATE GRADE, DEFORMED AND SHALL CONFORM TO A.S.T.M. SPEC DESIGNATION A15
CONCRETE SLAB ANCHOR 90° BENDS
24" STEAM MAIN - 400 PSI
CONSOLIDATED EDISON COMPANY OF N.Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU
DATE 3-11-55
LAST REV.
DWG. NO. EO-7095-B REV. 0
FIG. 4

EO-6852-C

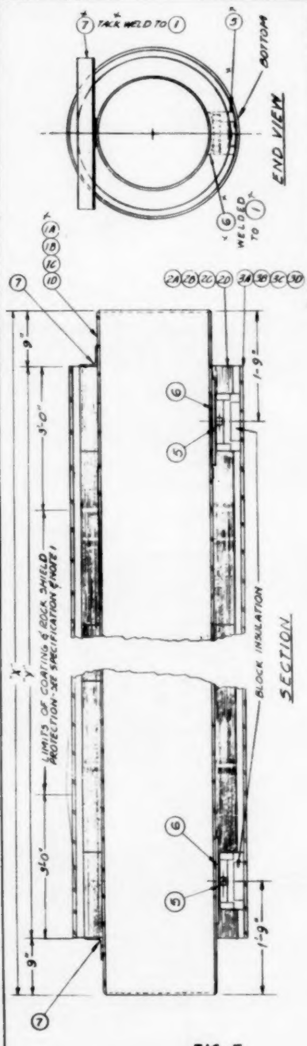


FIG. 5

BILL OF MATERIAL

ITEM NO.	QUAN.	LENGTH	DESCRIPTION	DWG OF SPEC.
1A,1B, 1C & 1D	1	"X"	24" O.D. X 3/8" WALL STD. STEEL PIPE	EO-9000
2A,2B, 2C & 2D	1	"Y"	24" I.D. X 4" THICK UNIBESTOS PIPE INSULATION	EO-9004
3A,3B, 3C & 3D	1	"Y"	36" O.D. X 3/8" WALL STD. STEEL PIPE	EO-1035
5	2	—	CAST IRON SUPPORT WITH ROLLER FOR 24" O.D. PIPE	EO-6867-D
6	2	—	BEARING PLATE 18" X 10" X 5/8" FLAT STEEL	SEE DETAIL
7	2	2'-8"	4" X 4" X 3/8" STEEL ANGLE (TEMPORARY)	SEE NOTE 2

DIMENSIONS

ITEM NO.	"X"	"Y"
1A, 2A & 3A	40'-0"	38'-6"
1B, 2B & 3B	27'-0"	25'-6"
1C, 2C & 3C	13'-0"	11'-6"
* 1D, 2D & 3D	10'-0"	8'-6"

APPROX. WEIGHT 40'-0" LENGTH - POUNDS

24" O.D. X 3/8" W.T. PIPE	5000
36" O.D. X 3/8" W.T. PIPE	7300
38'-6" LG. X 4" THICK INSULATION	1340
BEARING PLATE, SUPPORT ETC.	140
TOTAL	13,780

SPECIFICATIONS:

THE SECTIONS OF UNIBESTOS INSULATION SHALL BE TIGHTLY BUTTED TOGETHER AND JOINTS WRAPPED WITH ONE LAYER OF ASBESTOS TAPE.

UNIBESTOS INSULATION SHALL BE CUT TO FIT THE OPEN SPACES IN THE PIPE PROTECTION SADDLE.

24" STEEL PIPE SHALL BE FABRICATED IN ACCORDANCE WITH SPECIFICATION EO-9000. ENDS SHALL BE BEVELED FOR WELDING IN ACCORDANCE WITH SPECIFICATION EO-1064.

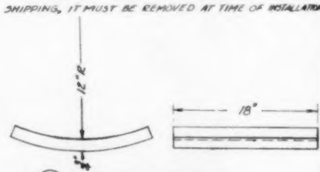
COATING SHALL BE IN ACCORDANCE WITH CON. EDISON CO. SPEC. EO-9005.

PIPE SHALL BE PROTECTED WITH ROCK SHIELD - LINE PRODUCTS CO. OR EQUAL - APPLIED IN ACCORDANCE WITH CON. EDISON CO. SPEC. EO-8063.

NOTES:-

*1- ITEM 1D SHALL NOT BE COATED OR PROTECTED WITH ROCK SHIELD.

2- ITEM 7 IS INTENDED TO PREVENT MOVEMENT DURING SHIPPING, IT MUST BE REMOVED AT TIME OF INSTALLATION.



6 BEARING PLATE
MAT'L. 18" X 10" X 5/8" FLAT STEEL

THIS DRAWING IS PART OF SPEC. EO-9007.

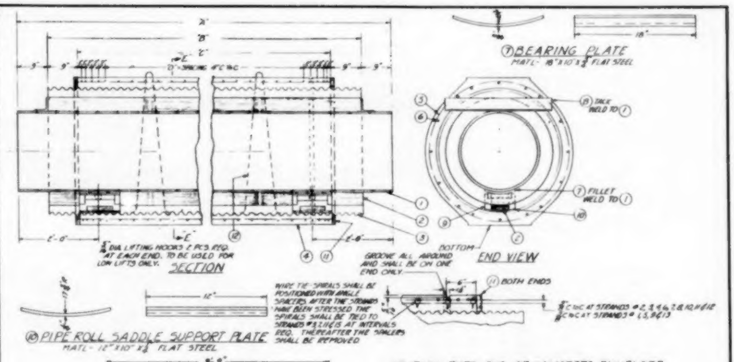
REFERENCE DWG.:-
STEEL SLEEVE ———— EO-6880-D

PREFABRICATED 24" STEAM MAIN
STEEL SHELL CONSTRUCTION 400 PSI

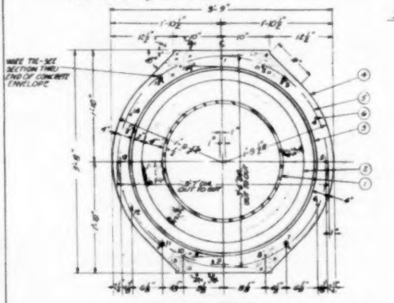
CONSOLIDATED EDISON COMPANY OF N. Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU

DATE 10-13-54 LAST REV. 4-29-55 DWG. NO. EO-6852-C REV. 5

EO-7143-B



SECTION THRU END OF CONCRETE ENVELOPE



SECTION E-E

SPECIFICATIONS

1. PIPE ENDS SHALL BE PREPARED FOR WELDING IN ACCORDANCE WITH CON EDISON CO. SPEC. EO-1066.
2. THE SECTIONS OF UNIBESTOS INSULATION SHALL BE TIGHTLY BUTTED TOGETHER AND JOINTS WRAPPED WITH ONE LAYER OF ASBESTOS TAPE.
3. UNIBESTOS INSULATION SHALL BE CUT TO FIT THE OPEN SPACES IN THE CAST IRON SADDLE BOX.
4. THE CORRUGATED METAL PIPE SHALL BE GALVANIZED. AFTER GALVANIZING THE PIPE SHALL BE DOUBLE DIPPED WITH AN ASPHALT COATING HAVING A MINIMUM COATING THICKNESS OF 1/8". THE ASPHALT COATING SHALL HAVE A SOFTENING POINT OF NOT LESS THAN 200°F.
5. CONCRETE SHALL TEST 3500 PSI AT TIME OF TRANSFER OF PRESTRESSING STRESSES.
6. ITEM 5, 1/4" DIA SPIRALS SHALL BE OF COLD DRAWN WIRE.
7. LONGITUDINAL STRANDS SHALL BE PRETENSIONED TO AN INITIAL TENSION FORCE OF 10,000 LBS PER STRAND. THE STRANDS SHALL BE 7 WIRE 3/8" DIA STRESS RELIEVED. MINIMUM ULTIMATE TENSION 15,000 LBS PER STRAND. 2 - .196" DIA. HIGH TENSION WIRES MAY BE SUBSTITUTED FOR EACH 3/8" DIA STRAND. MINIMUM ULTIMATE TENSION PER WIRE SHALL BE 7500 LBS. INITIAL PRETENSION FORCE PER WIRE SHALL BE 5000 LBS.

TABLE OF DIMENSIONS FOR UNITS

"A" LENGTH ITEM 1	"B" LENGTH ITEMS 2 & 3	"C" LENGTH ITEMS 4 & 6	"D"-ITEM 5 NO. TURNS AT 4" C to C	"D"-ITEM 5 LENGTH	"D"-ITEM 5 TOTAL NO. TURNS REQ.
40'-0"	38'-6"	37'-0"	107	35'-8"	116
27'-0"	25'-6"	24'-0"	68	22'-8"	77
20'-0"	18'-6"	17'-0"	47	15'-8"	56
13'-0"	11'-6"	10'-0"	26	8'-8"	35
10'-0"	8'-6"	7'-0"	17	5'-8	26

APPROXIMATE WEIGHT 40' LENGTH IN POUNDS	
24" O.D. x 1/2" WALL STANDARD STEEL PIPE 40'-0" LONG	5020
24" I.D. x 4" THICK UNIBESTOS PIPE INSULATION	1600
36" I.D. CULVERT PIPE 16 GA. CORRUGATED METAL	970
21.4 CU. YDS REINFORCED CONCRETE	28,900
CAST IRON SADDLE BOX & ROLLER, BEARING PLATES ETC	130
TOTAL	36,620

NOTE:-
ITEM 8 IS INTENDED TO PREVENT MOVEMENT DURING SHIPMENT, IT MUST BE REMOVED AT THE TIME OF INSTALLATION.

ENDS OF CORRUGATED METAL PIPE SHALL BE SEALED TO PROTECT THE INSULATION FROM BECOMING WET.

FIG. 6

THIS DRAWING IS PART OF CON EDISON CO. SPEC. EO-9008

THIS DRAWING SUPERSEDES DRAWING NO. EO-6948-C

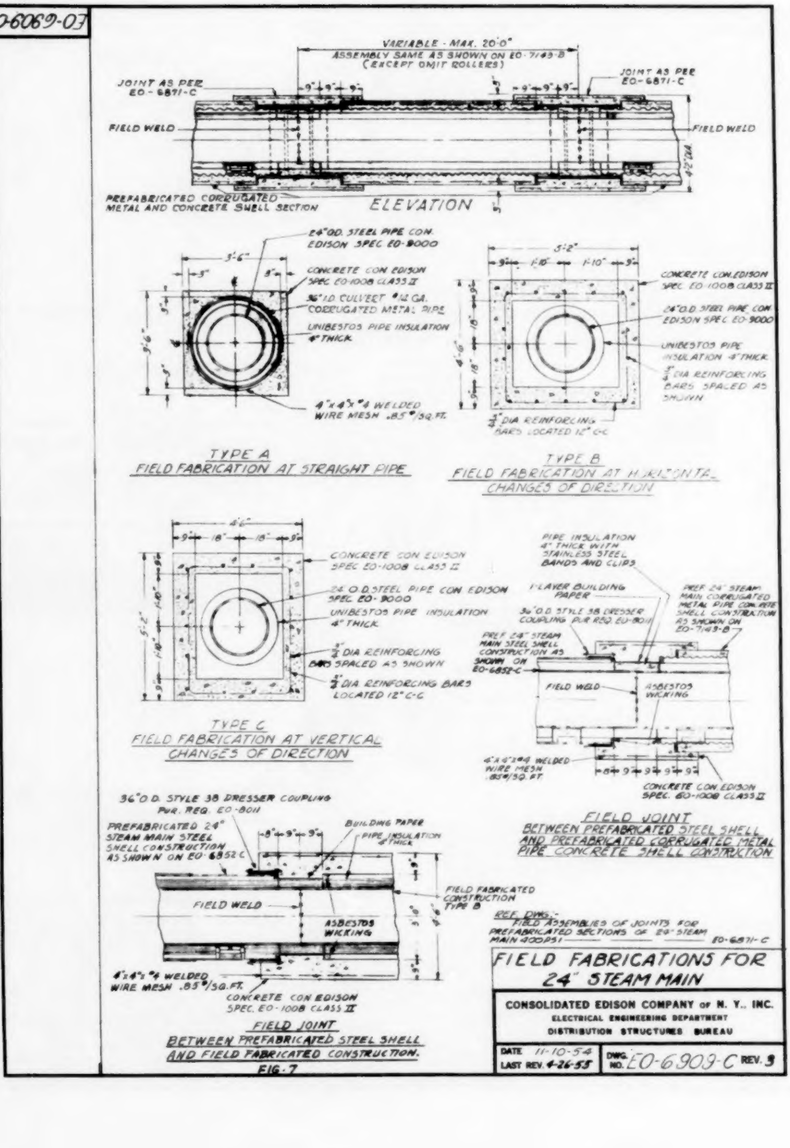
ITEM NO	QUANTITY	LENGTH	DESCRIPTION	DWG. OR SPEC. NO.
12	4	8'-0"	LIFTING HOOK - 5/8" DIA. ST'L ROD-AS SHOWN	——
11	AS SHOWN	——	1" THICK "FLEXCEL"	——
10	2 PER UNIT	——	PIPE ROLL SADDLE SUPPORT PLATE - SEE DETAIL	——
9	2 PER UNIT	——	CAST IRON SADDLE BOX & ROLLER FOR 24" O.D. PIPE	EO-6967-C
8	2 PER UNIT	2'-8"	BRACKET 4" X 4" X 1/2" STEEL ANGLE	——
7	2 PER UNIT	18"	BEARING PLATE - SEE DETAIL	——
6	16	SEE UNIT DIM. "C"	3/8" DIA STRANDS	——
5	SEE UNIT DIM. "D"	SEE UNIT DIM. "D"	1/4" DIA. SPIRALS - 42" O.D. VERT. 45" O.D. HOR.	——
4	CU. YDS. AS REQ.	SEE UNIT DIM. "C"	CONCRETE CLASS I	EO-1008
3	——	SEE UNIT DIM. "B"	36" I.D. CULVERT PIPE 16 GA. CORRUGATED METAL	——
2	——	SEE UNIT DIM. "B"	24" I.D. x 4" THICK UNIBESTOS PIPE INSULATION	EO-9004
1	——	SEE UNIT DIM. "A"	24" O.D. x 1/2" WALL STANDARD STEEL PIPE	EO-9000

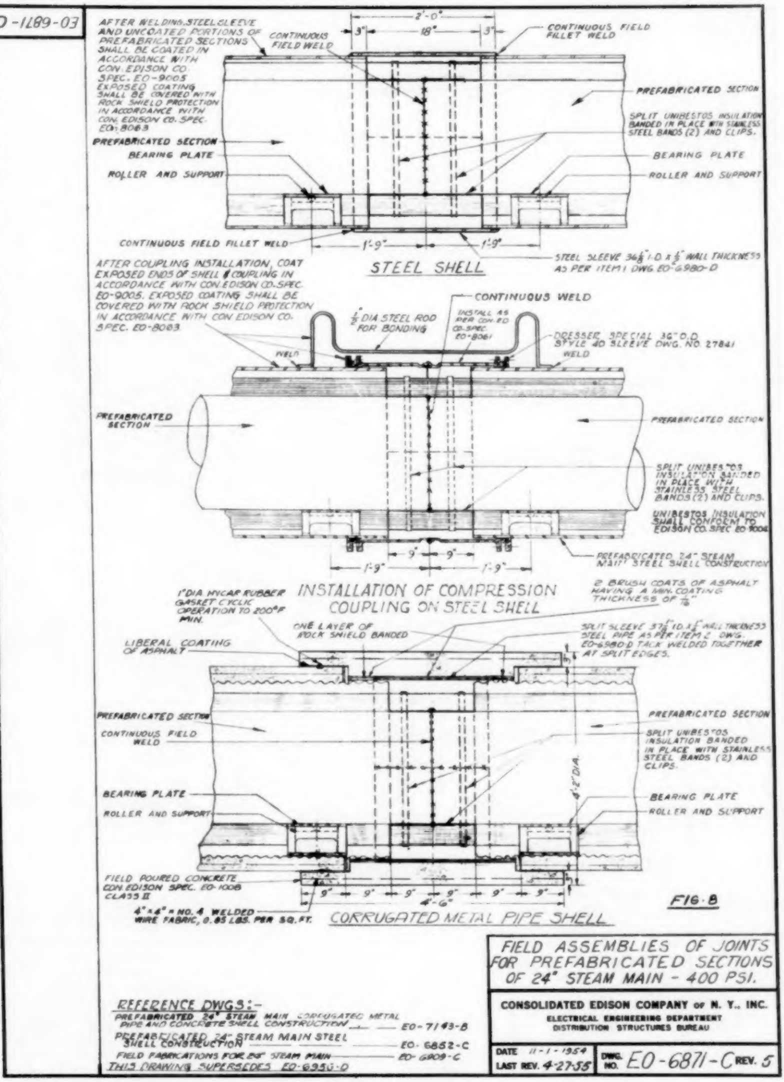
BILL OF MATERIAL

PREFABRICATED 24" STEAM MAIN
CORRUGATED METAL PIPE AND
CONCRETE SHELL CONSTRUCTION

CONSOLIDATED EDISON COMPANY of N.Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU

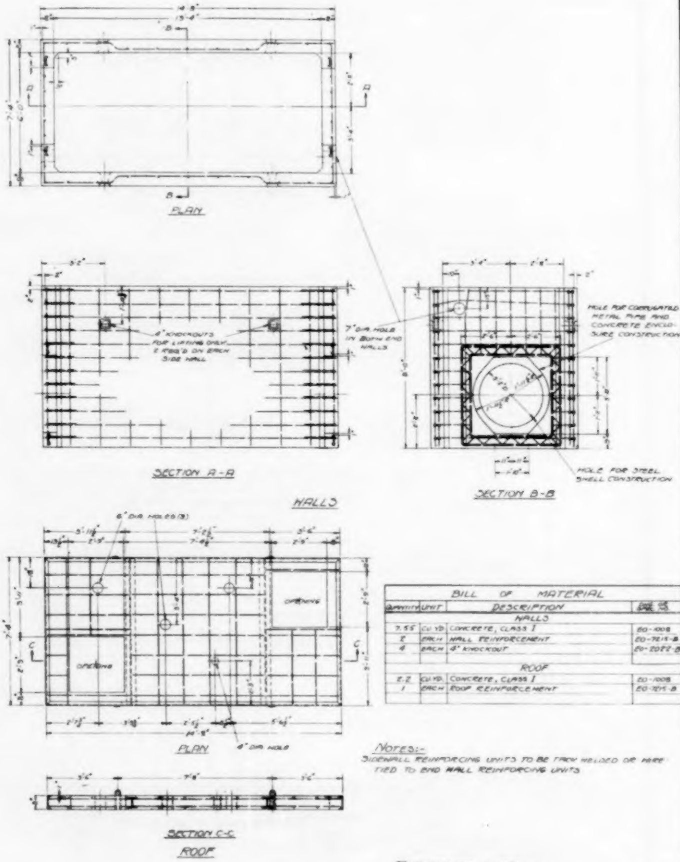
DATE 4-16-55 LAST REV. DWG. NO. EO-7143-B REV. 0


VARIABLE - MAX. 20'0"
ASSEMBLY SAME AS SHOWN ON EO-7143-B (EXCEPT OMIT ROLLERS)
JOINT AS PER EO-6871-C
FIELD WELD
PREFABRICATED CORRUGATED METAL AND CONCRETE SHELL SECTION
ELEVATION
24" O.D. STEEL PIPE CON. EDISON SPEC EO-9000
CONCRETE CON EDISON SPEC EO-1008 CLASS II
36" I.D. CULVERT #12 GA. CORRUGATED METAL PIPE
UNIBESTOS PIPE INSULATION 4" THICK
4"x4"x#4 WELDED WIRE MESH .85#/SQ.FT.
TYPE A
FIELD FABRICATION AT STRAIGHT PIPE
UNIBESTOS PIPE INSULATION 4" THICK
DIA REINFORCING BARS SPACED AS SHOWN
DIA REINFORCING BARS LOCATED 12" C-C
TYPE B
FIELD FABRICATION AT HORIZONTAL CHANGES OF DIRECTION
TYPE C
FIELD FABRICATION AT VERTICAL CHANGES OF DIRECTION
PIPE INSULATION 4" THICK WITH STAINLESS STEEL BANDS AND CLIPS
1-LAYER BUILDING PAPER
36" O.D. STYLE 38 DRESSER COUPLING PUR REQ. EO-8011
PREF 24" STEAM MAIN CORRUGATED METAL PIPE CONCRETE SHELL CONSTRUCTION AS SHOWN ON EO-7143-B
PREF 24" STEAM MAIN STEEL SHELL CONSTRUCTION AS SHOWN ON EO-6852-C
ASBESTOS WICKING
CONCRETE CON EDISON SPEC. EO-1008 CLASS II
FIELD JOINT
BETWEEN PREFABRICATED STEEL SHELL AND PREFABRICATED CORRUGATED METAL PIPE CONCRETE SHELL CONSTRUCTION
PREFABRICATED 24" STEAM MAIN STEEL SHELL CONSTRUCTION AS SHOWN ON EO-6852 C
BUILDING PAPER
PIPE INSULATION 4" THICK
FIELD FABRICATED CONSTRUCTION TYPE B
FIELD JOINT
BETWEEN PREFABRICATED STEEL SHELL AND FIELD FABRICATED CONSTRUCTION.
FIG. 7
REF. DWG:- FIELD ASSEMBLIES OF JOINTS FOR PREFABRICATED SECTIONS OF 24" STEAM MAIN 400PSI EO-6871-C
FIELD FABRICATIONS FOR 24" STEAM MAIN
CONSOLIDATED EDISON COMPANY OF N. Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU
DATE 11-10-54
LAST REV. 4-26-55
DWG. NO. EO-6909-C REV. 3



STEEL SHELL
INSTALLATION OF COMPRESSION COUPLING ON STEEL SHELL
CORRUGATED METAL PIPE SHELL
FIG. 8
FIELD ASSEMBLIES OF JOINTS FOR PREFABRICATED SECTIONS OF 24" STEAM MAIN - 400 PSI.
CONSOLIDATED EDISON COMPANY OF N. Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU
REFERENCE DWGS:-
PREFABRICATED 24" STEAM MAIN CORRUGATED METAL PIPE AND CONCRETE SHELL CONSTRUCTION EO-7143-B
PREFABRICATED 24" STEAM MAIN STEEL SHELL CONSTRUCTION EO-6852-C
FIELD FABRICATIONS FOR 24" STEAM MAIN EO-6909-C
THIS DRAWING SUPERSEDES EO-6956-D
DATE 11-1-1954
LAST REV. 4-27-55
DWG. NO. EO-6871-C REV. 5

E-9669-07



BILL OF MATERIAL			
QUANTITY	UNIT	DESCRIPTION	DWG OR SPEC NO.
		WALLS	
7.55	CU. YD.	CONCRETE, CLASS I	EO-1008
2	EACH	WALL REINFORCEMENT	EO-7215-B
4	EACH	4" KNOCKOUT	EO-2022-B
		ROOF	
2.2	CU. YD.	CONCRETE, CLASS I	EO-1008
1	EACH	ROOF REINFORCEMENT	EO-7215-B

NOTES:-
SIDEWALL REINFORCING UNITS TO BE TACK WELDED OR WIRE TIED TO END WALL REINFORCING UNITS

REFERENCE DWG'S:-
PREFABRICATED REINFORCEMENT—EO-7215-B
CONCRETE BASE WITH ANCHOR—EO-7093-B
INSTALLATION EO-6975-B

VALVE MANHOLE TYPE S13-4
FOR 24" STEAM MAIN, 13'-4" × 6'-0" × 8'-0"
PRECAST CONCRETE

CONSOLIDATED EDISON COMPANY OF N.Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU

DATE 4-28-55 LAST REV. DWG. NO. EO-6936-B REV. 0

FIG. 9

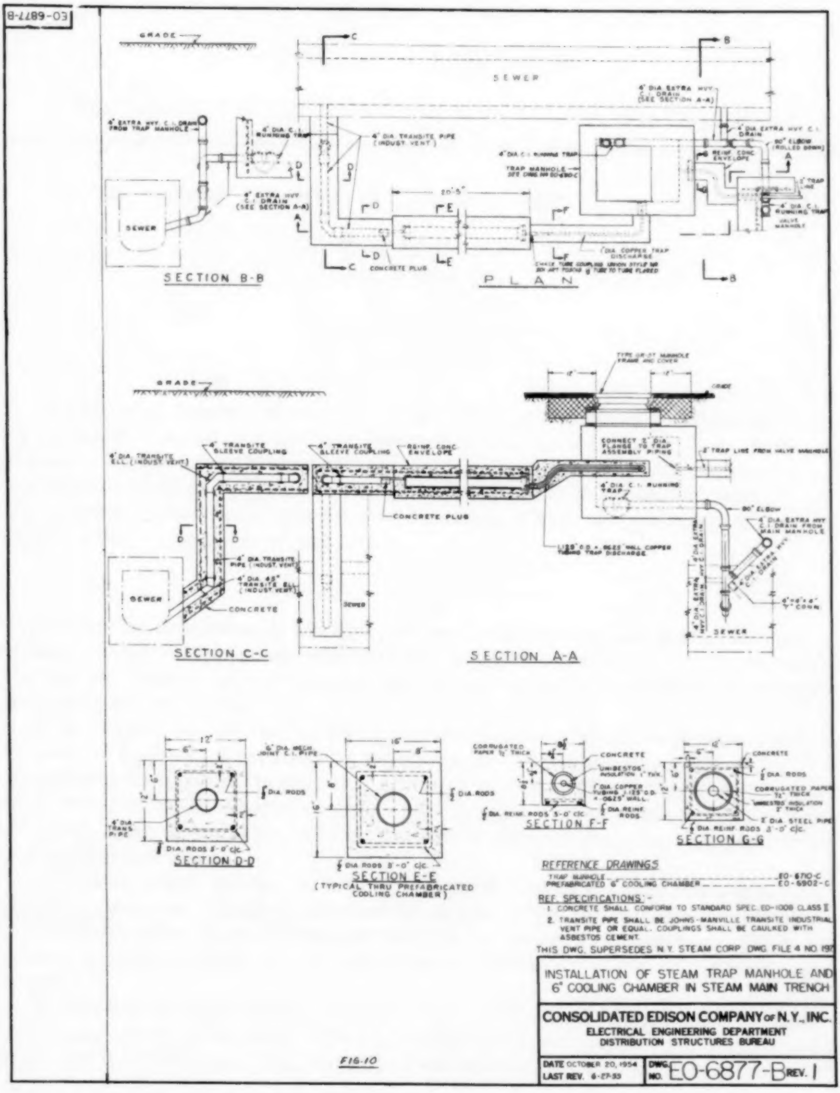

EO-6877-B
GRADE
SEWER
SECTION B-B
PLAN
SECTION C-C
SECTION A-A
SECTION D-D
SECTION E-E
(TYPICAL THRU PREFABRICATED COOLING CHAMBER)
SECTION F-F
SECTION G-G
REFERENCE DRAWINGS
REF. SPECIFICATIONS:-
1. CONCRETE SHALL CONFORM TO STANDARD SPEC. EO-1008 CLASS II
2. TRANSITE PIPE SHALL BE JOHNS-MANVILLE TRANSITE INDUSTRIAL VENT PIPE OR EQUAL. COUPLINGS SHALL BE CAULKED WITH ASBESTOS CEMENT.
THIS DWG. SUPERSEDES N.Y. STEAM CORP. DWG. FILE 4 NO. 197
INSTALLATION OF STEAM TRAP MANHOLE AND 6" COOLING CHAMBER IN STEAM MAIN TRENCH
CONSOLIDATED EDISON COMPANY OF N.Y., INC.
ELECTRICAL ENGINEERING DEPARTMENT
DISTRIBUTION STRUCTURES BUREAU
DATE OCTOBER 20, 1954
LAST REV. 6-27-55
DWG. NO. EO-6877-B REV. 1

FIG-10

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

SECONDARY STRESSES IN LARGE-DIAMETER PIPELINES[1]

G. M. McClure[2]
(Proc. Paper 1280)

ABSTRACT

There are a number of sources of secondary stresses in line pipe during shipment of the pipe and during construction and operation of a line. Predominant secondary stresses are discussed, and some examples of their magnitudes given. Stresses and localized points are the most significant. To eliminate detrimental stresses of this type, a high test pressure after construction is considered important.

During the past decade, the state of knowledge of pipeline design has advanced significantly. Along with this advancement, there has developed an increasing interest in some of the "secondary" loads and resulting stresses that can exist in a line.

It is the purpose of this paper to discuss some of the more predominant sources of secondary stresses in pipelines, to give some examples of the magnitudes of these stresses, and, further, to discuss their significance and how they may be eliminated or taken into account in the design and operation of a line. The discussions will not include compressor stations or regulator and metering stations.

Let a secondary stress be defined as any stress in the line other than the nominal values produced by internal pressure. This is a broader definition than usually used since it does not restrict the extent of the stress. Stresses at very localized points are included, in addition to stresses acting over large areas.

A convenient way to define the extent of a stress was suggested by Kuhn(1) in a paper given in January, 1956, at the International Conference on Fatigue in Aircraft Structures. His classification was specifically applied to aircraft

Note: Discussion open until November 1, 1957. Paper 1280 is part of the copyrighted Journal of the Pipelines Division of the American Society of Civil Engineers, Vol. 83, No. PL 2, June, 1957.

1. Presented at the Convention of the American Society of Civil Engineers, Pipelines Division, Jackson, Miss., February 18, 1957.
2. Asst. Chief, Applied Mechanics Div., Battelle Memorial Inst., Columbus, Ohio.

structures; however, it offers a very convenient method for defining the problem of secondary stresses in pipelines. He defined four types of stresses according to the length over which the stress acts. The four types are called: "fathom" stresses, "foot" stresses, "inch" stresses, and "millimeter" stresses.

Fathom stresses are essentially constant for a length of about six feet and can ordinarily be calculated with good accuracy from ordinary engineering formulas. (This is not always possible in a pipeline or other buried structure, however, because the loads and restraints are not always known, especially when soil loads are involved.) The fathom was chosen because it is the only unit falling in the desired range. Foot stresses exist over lengths on the order of a foot and can also be calculated in most cases by known but slightly more refined engineering formulas. Inch stresses such as occur in a generous fillet must usually either be estimated or measured. Millimeter stresses are those which exist, for example, at the root of a sharp notch or around a small rivet hole, and can only be estimated since they cannot be measured by ordinary methods. In what follows, this rather unique method of classifying stresses will be used in considering the relative importance of secondary stresses in pipelines and in pointing out how such stresses can be taken into account in the design and operation of a line.

Sources of Secondary Stress

Let us now review some of the more prominent sources of secondary stresses in pipelines starting with the time that the pipe leaves the mill.

Shipping

One possible source of rather high stresses that is sometimes overlooked can occur during shipment of the pipe from the mill to the job site. Let us assume we are dealing with a case of rail shipment where the pipe is stacked several layers high on a railroad car—the height of the stack depending on the pipe diameter. Normally, the stack is set on cribbing layed across the floor of the car—2 inch x 6 inch or 2 inch x 8-inch lumber is commonly used. If the spacing between the cribbing is too large, quite high local stresses can occur in the pipe wall adjacent to the cribbing.

Figure 1 shows stresses that can occur in 30-inch-diameter pipe of various wall thicknesses for various cribbing spacings. The assumed method of stacking is indicated in the figure. The stresses are localized bending stresses in the wall of the bottom layer of pipe just above the cribbing; they were calculated by a method suggested by Roark.(2) They are static stresses and can be classed as inch stresses, as defined above.[3]

During shipment, a certain amount of bouncing of the car occurs and accelerations of 3 g are possible. Thus, alternating stresses on the order of three times those indicated in Figure 1 are possible and the space between the cribbing on the bottom should be picked to keep these stresses well below the endurance limit of the steel.

---

3. In calculating the stresses in Figure 1, it was necessary to assume the area of contact between the pipe wall and the cribbing. The exact area would vary appreciably with the type of wood used for the cribbing. For this reason, the stresses shown should be considered approximate.

This is a rather straightforward case of secondary stresses, but is mentioned here because, in at least one instance in the past, it is known that fatigue cracks (which later caused leaks during test) developed in the pipe wall in shipment.

Construction

During construction, a number of things can happen which produce high secondary stresses. Some of these introduce the stress immediately, some produce irregularities which might later lead to high secondary stresses when pressure is introduced in the line, and some involve a combination of both.

Of course, the practice of welding the line together above ground on skids and then lowering it intact into the ditch leads to longitudinal bending stresses that can vary quite widely. These are a function of the weight of the pipe, the load applied by the backfill, and the accuracy with which the contour of the bottom of the ditch matches the "unstressed" contour of the pipe.

One example of this type of secondary stress was obtained in some strain-gage measurements made by Battelle engineers several years ago during the construction of a 30-inch line. Bonded-wire strain gages were applied to the line at two locations about 85 feet apart while the line was still above ground on skids. Figure 2 shows the strain-gage locations. One ring of gages was applied on straight pipe and the other in a 6-degree sag bend. By comparison of readings of the gages before and after the line was lowered into the ditch and backfilled, it was possible to determine the "residual" longitudinal stresses in the line as installed in the ditch. Figure 3 shows the longitudinal stresses left in the line after it had been backfilled. It can be seen that some bending existed at both gage locations—relatively little in the straight pipe and appreciable in the sag. This example illustrates that, even with careful attention to field bends to make the line conform to the bottom of the ditch, appreciable longitudinal stresses can be produced. Such stresses would be classed as fathom stresses.

Several other possible sources of high secondary stresses originate during construction. One is deformation of the pipe out-of-round such as might occur during handling or in field bends. An example of this is shown later.

Two of the most troublesome sources during construction are the inadvertent production of dents in the pipe wall and the occurrence of cracks in girth welds—from which inch and millimeter stresses, respectively, are produced. Both of these are sometimes hard to detect during inspection. Their significance is also discussed later.

Operation

In reviewing the secondary stresses during the operational life of a line, it is convenient to classify the stresses that can occur according to the primary load that produces the stress. High stresses result from the action of three basic loads during operation—internal pressure, temperature change, and external loads on the line.

Internal Pressure Loads

By virtue of the definition chosen for secondary stresses, internal pressure can produce high secondary stresses only in the presence of some sort of irregularity in the pipe. For example, when the pipe is out-of-round, the

internal pressure tends to make it become round and, in doing so, produces bending stresses in the wall which are tension in some locations and compression in others. These can normally be classified as foot stresses. Localized out-of-roundness such as dents in the wall can produce very high bending stresses, usually of the inch type.

At branch connections or other fittings where the cylindrical symmetry of the pipe is interrupted, localized bending stresses can also exist. These are usually of the inch or millimeter type.

Probably the highest secondary stress produced by the action of internal pressure is in defects such as weld cracks. In these cases, only a very small volume of metal is affected and these can be classed as millimeter stresses.

Examples of the magnitudes of some of the secondary stresses resulting from internal pressure are available from experimental work that has been done in the past.

One example is from the results of the strain-gage measurements made at the sag bend shown in Figure 2. It was found that the pipe was out-of-round in this bend and stresses above the yield occurred when internal pressure was introduced during the hydrostatic test after construction. Figure 4 shows the stresses determined at two pressures from the strain-gage readings taken during the test. The approximate cross section, determined from diameter measurements before the test is shown in the center of the plot. Comparison of the cross section and the stress curves furnishes an explanation for the high stresses that occurred at the bottom and sides of the pipe. At these locations the pipe wall had been somewhat flattened (that is, the radius of curvature was greater than 15 inches) and internal pressure tended to make the wall assume a radius of 15 inches again, thus producing high tension stresses on the outer surface where the strain gages were placed.

Quite a number of investigations have been carried out to determine stresses in reinforced branch connections. One extensive project was completed at Battelle last year for the American Gas Association; the results of this investigation will soon appear in an A.G.A. research report. In this work, three different sizes of branch connections and three different types of reinforcements (pad, the saddle, and the full-encirclement sleeve) were investigated under internal pressure and two different external bending loads applied to the branch pipe. The results of the investigation are too extensive to describe here; however, it was found that with the type of reinforcements that would be fabricated in the field (as opposed to forged tees), stresses on the order of the yield strength of the pipe can occur at operating pressures.

Temperature Changes

Changes in temperature during the life of the line, of course, produce varying longitudinal stresses. In long, straight sections of buried line these can be easily predicted since the line can be assumed to be completely restrained in the longitudinal direction.

At sharp changes in direction or around branch connections the pipe is not completely restrained by the soil and high bending stresses can result from temperature changes of the line. Usually these stresses cannot be accurately calculated because the restraints on the pipe from the soil are not accurately known.

Measurements of the long-time variations in longitudinal stress that result from temperature changes are not easily made. This is because the changes take place over a fairly long period of time and it is very hard to maintain

stability in a sensitive strain-measuring device over a period of time. Progress is being made along these lines, however, and quite a few operating companies are now undertaking experimental programs to determine stresses at critical points in their lines. The results should be available within a year or so.

External Loads

Some of the more prominent external loads that can produce secondary stresses in a pipeline include the weight of the backfill, traffic loads at uncased road crossings, and any earth movement or settlement that occurs.

The backfill loads and traffic loads tend to deform the pipe to an elliptical shape and thus produce bending stresses in the wall.

Manning and Lodge at Battelle performed some experiments several years ago on buried 20-inch-diameter by 1/4-inch wall pipe to determine the initial backfill stresses and also how they might vary over a period of time.[3] With internal pressure in the pipe of 900 psi, the initial backfill stresses were found to be on the order of 1000 psi. Over a year's time, however, as the backfill settled, the bending stresses produced by the backfill were found to increase and the maximum variation observed was on the order of 1900 psi—about 6 per cent of the nominal pressure stress.

Professor Spangler at Iowa State made an analysis of backfill loads and traffic loads.[4] He showed, for example, that in a 30-inch-diameter x 3/8-inch wall pipe with 3 feet of backfill and 800 psi internal pressure, the initial backfill loads can be as high as 9 per cent of the nominal design hoop stress and the combination of backfill and truck loads might reach values as much as 20 per cent above nominal design stress.

Stresses resulting from these two external loads can be classed as fathom or foot stresses.

Designing for Secondary Stresses

After discussing some of the sources of secondary stresses in pipelines, the logical question is "What do we do to take these into account in the design and operation of a line?" As evidenced by the successful operation of many thousands of miles of lines built in the last 10 years, the pipeline industry now has good methods of doing this. As previously noted, however, the problem of how to treat secondary stresses is a complicated one and very few engineers are willing to state that they know enough about the subject. Continuing effort is needed to define these stresses even more accurately.

In attempting to answer the question above, it would be well to point out the significance of the secondary stresses that have been discussed.

Experience has shown that nearly all leaks or failures in lines originate in some type of stress concentration—where stresses of the inch or millimeter type exist. The more gross foot and fathom stresses have often played a part also. A lot of leaks that occur, do so (after a number of years of operation) at a pressure lower than some previous pressure to which the pipe was subjected. One explanation for this is that in the area of the inch or millimeter stress at the leak, a foot or fathom stress appeared or increased during operation. As previously pointed out, secondary stresses from temperature changes and backfill or traffic loads can vary quite widely with time. If they happen to reach an especially high value in an area where an inch or millimeter stress already exists, the total combined stress there might be higher

than existed during the original test of the line, and an apparently unexplainable leak could occur.[4]

Thus, experience has indicated that localized stresses (especially the millimeter type) are of primary significance, and that the fathom stresses, acting over a large area are not detrimental, if acting alone. The basic reasons for this behavior can be explained by the different states of stress that exist in the two cases. To illustrate this point, consider two tensile specimens of a medium carbon steel—one unnotched and one containing a sharp notch. The ductility exhibited by each is a function of the relative magnitudes of the normal stresses and the shear stresses in the specimen. The unnotched specimen, of course, represents a uniaxial stress case—that is, the maximum tensile stress exists in one direction only and there is a maximum shear stress equal to one-half of the tensile stress. The ratio of the maximum normal stress to the maximum shear stress is relatively low. This specimen remains quite ductile, even when tested to temperatures as low as -100 F, and finally fails by a shear fracture.[(5)]

In the notched specimen, however, the sharp notch drastically alters the state of stress in a small volume of metal at the base of the notch. A state of triaxial stress exists there with tension stresses in all three directions. This raises the ratio of maximum normal stress to maximum shear stress and decreases the ductility of the material at that point. The notched specimen when tested below temperatures in the range of 20-30 F might exhibit very little ductility and fail by cleavage[(5)] (the temperature here depends on many factors, including the chemical composition and previous stress history).

Referring again to secondary stresses in pipelines—the foot and fathom stresses can be likened to the unnotched tensile specimen. The state of stress is such that the pipe material has the ability to yield and in doing so, either relieve or accept the load producing the stress without failure. The millimeter stresses might represent the notched tensile specimen with a higher stress ratio and less inherent ductility.

Of course, the obvious method of insuring a successful pipeline is to eliminate the inch and millimeter stresses and minimize the foot and fathom secondary stresses. (The latter cannot be completely eliminated since some are produced by loads that vary throughout the life of a line.) Careful design is, of course, the first step—where the best available materials and methods can be prescribed in order that potential sources of high secondary stresses are not built into a line. Design methods have improved greatly in the past decade, and as pointed out previously, work is going on in the industry to gain more information on some of the stresses not yet completely defined.

Good construction practices and close inspection during construction are also very important. Here again there has been a lot of advancement in recent years with the manufacture of improved heavy equipment, and the development of improved welding techniques, X-ray, and other inspection methods.

All of these improvements in design and construction have gone a long way toward eliminating potential sources of high secondary stresses. The proof of the pudding, so to speak, is the test after construction. This test is important in two main respects. First, it serves as a test of the tightness of the line, and any leaks that exist can be found and repaired. Second, it provides a means of detecting and removing any sources of high secondary

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4. It is assumed here that corrosion is not a factor.

stresses that were missed during inspection or introduced after inspection. To do this effectively, the test must subject the line to stress levels higher than will occur later during operation in order to account for the secondary stresses produced by temperature and external loads which vary during the life of a line. Since we do not have accurate data on the range over which these stresses vary, the best assurance that all of the detrimental inch and millimeter stresses are detected is to use as high a test pressure as is feasible. Testing to pressures producing a nominal circumferential stress equal to the minimum specified yield strength of the pipe, or above, is considered by the author to be desirable (if practical in the field operations). In doing so, the line is "proved" to a maximum possible per cent above the operating stresses. Such practice would undoubtedly produce yielding at some locations in the line. Yielding is not considered serious, however, except at points where the pipe material has low ductility—such as the millimeter stress points discussed above. Any of these points that are severe will show up as leaks during the test and the pipe containing them can then be replaced before the line is put in operation.

CONCLUDING REMARKS

To summarize, the following observations and conclusions have been discussed:

(1) Secondary stresses are produced by three basic loads; external forces on the line, temperature changes, and the effect of internal pressure at irregularities. (Corrosion is another possible factor—assumed for the discussions here to be nonexistent, however.)

(2) In general, secondary stresses produced by temperature changes and external loads are more variable throughout the life of a line than those produced by internal pressure.

(3) The localized stresses that exist over lengths of an inch or less are of primary concern in a pipeline (and in other structures) since experience has shown that all leaks or failures are originated at such points.

(4) The secondary stresses that exist over lengths on the order of a foot or greater are apparently not detrimental unless a localized stress is also present. Under such a "large-area" stress, the pipe material can yield and in many cases relieve the secondary stress. This is not true at a localized stress raiser where the material's ability to yield may be limited.

(5) A high test pressure is considered important to insure that none of the localized stresses exist in the line when operation begins.

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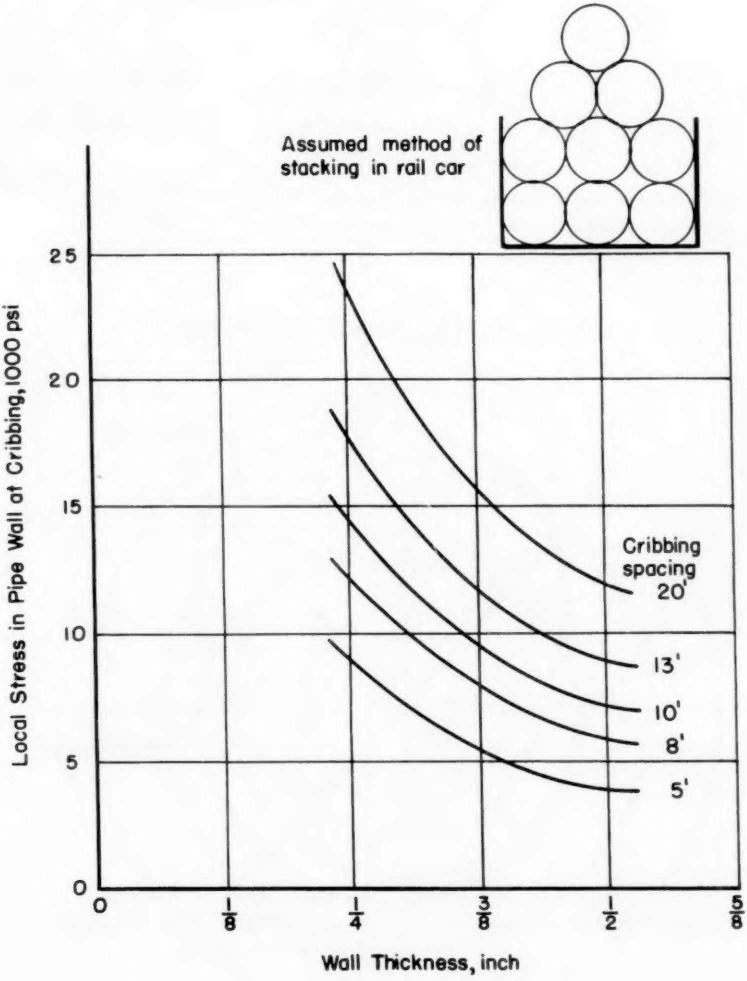


FIGURE 1. LOCAL STRESSES IN PIPE STACKED ON CRIBBING FOR VARIOUS WALL THICKNESSES AND CRIBBING SPACING

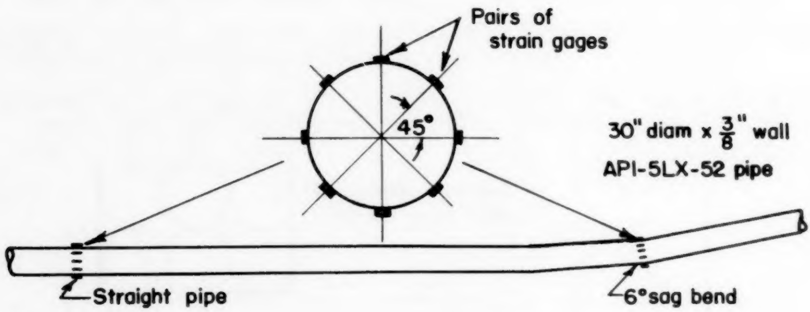


FIGURE 2. STRAIN GAGE LOCATIONS

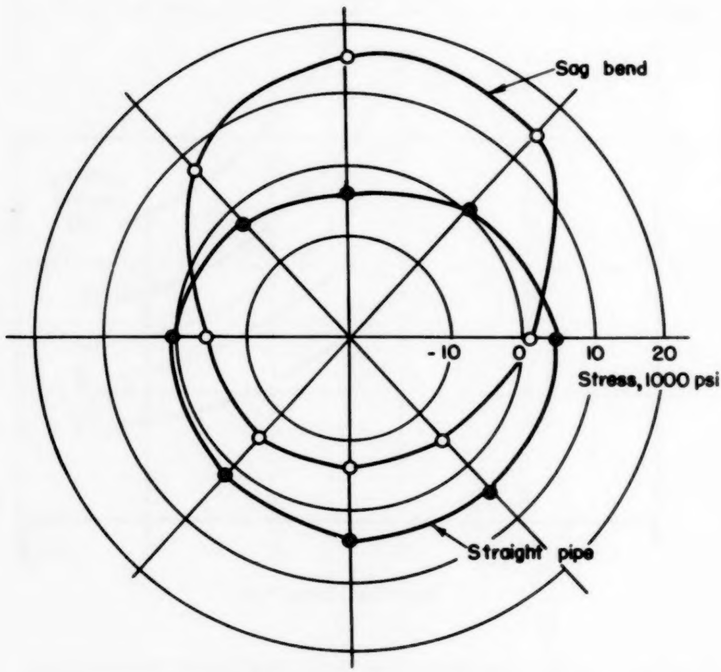


FIGURE 3. LONGITUDINAL STRESSES PRODUCED BY LOWERING-IN AND BACKFILLING

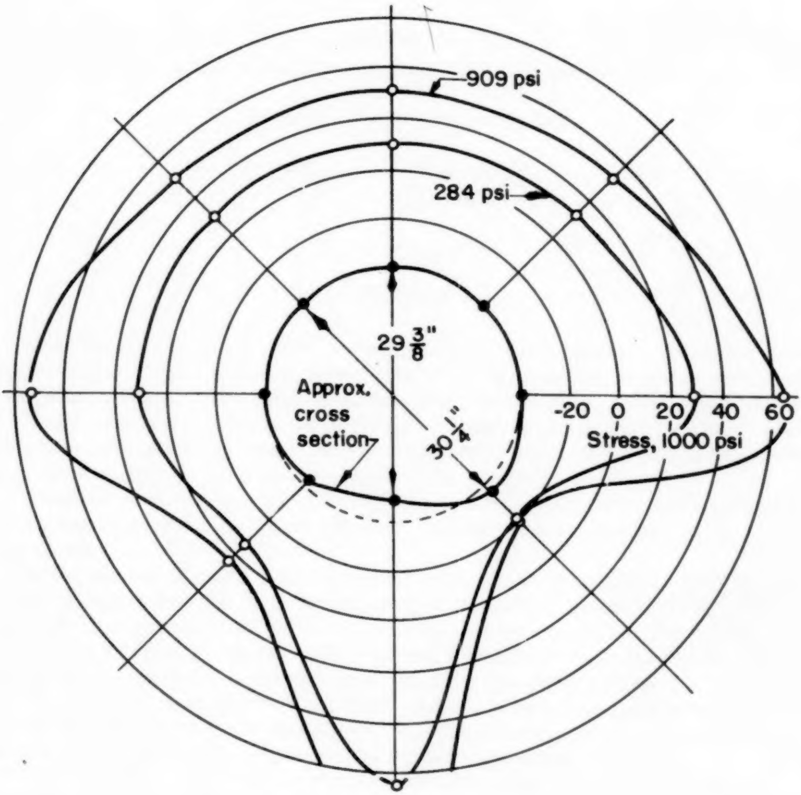


FIGURE 4. CIRCUMFERENTIAL STRESSES AT SAG BEND DURING TEST

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

PIPELINE RIVER CROSSINGS[a]

Leo M. Odom,[b] M. ASCE
(Proc. Paper 1281)

SYNOPSIS

Breaks in pipelines at river crossings were quite common up until a very few years ago. The steadily increasing sizes, pressures, lengths, and investments in pipelines have made it mandatory that the river crossings be constructed on a more permanent basis. For this reason pipeline river crossings are now receiving about the same degree of care in investigation, design, and construction as is given to railroad and highway crossings.

Pipeline river crossings are sometimes made by bridges, but underwater crossings are by far the most common largely because of lower first cost and maintenance.

In the design of underwater crossings the primary considerations peculiar to the problem are the counterbalancing of buoyancy, protection from external damage, and provision of strength to resist structural failure. The type of river and its geological, hydrological, and historical characteristics must be taken into account in the selection of the site, the design of the crossing, and the determination of the best working season. The design of a bridge involves somewhat the same investigations as the design of an underwater crossing plus certain additional considerations due to its exposure.

The specifications and testing required should be complete enough to guarantee that the crossing will be adequate and capable of serving its function for the contemplated life of the project. However, the methods and details of construction should be largely left to the discretion of the contractor. Construction methods and equipment are constantly changing as the problems involved become better understood and new ideas develop. Over-zealousness by engineers in specifying how the job shall be done could result in the blocking of one of the greatest sources of progress in pipelining, i.e., the ingenuity of the contractors.

Note: Discussion open until November 1, 1947. Paper 1281 is part of the copyrighted Journal of the Pipelines Division of the American Society of Civil Engineers, Vol. 83, No. PL 2, June, 1957.

a. Presented at Jackson Convention, American Society of Civil Engineers, February 18, 1957, Jackson, Miss.

b. Pyburn & Odom, Cons. Engrs., Baton Rouge, La.

INTRODUCTION

The design and construction of the crossing of a river for a large cross-country pipeline requires the ultimate in care and study. All large lines are normally flowing very near full capacity and the total disruption of service can seldom be avoided when a break occurs. The revenue of these lines alone is counted in thousands of dollars per hour and the disruption of service may also cause the additional loss of much greater sums because of shutdowns of factories. A break in the land portion of the line, while it results in considerable loss, can usually be repaired within a few hours, but a break in a river crossing usually occurs when the river is at a high stage and working conditions are very difficult and the line may be out of service for days or even weeks.

The first pipelines were small and flexible. The danger of disruption of such lines by river action was not great, nor was the monetary value of the service nearly so important as is the case with the modern big pipeline. When breaks occurred, service could be quickly restored by pulling another relatively inexpensive line across the river. The earlier large lines were constructed with about the same attitude as to the importance of the river crossings with the result that many breaks occurred. At the present time, however, in most cases the rivers are receiving a great deal of attention and no breaks in river crossings of large lines have come to the attention of the author within the last several years.

Pipelines carrying gas, crude oil and petroleum products under high pressures are built of welded steel pipe and this type of pipeline is the one specifically referred to in this paper. The problems involved in stream crossings of lower pressure water lines, which are usually built of cast iron pipe, are similar to a degree but have special facets of their own.

Pipeline work has, in all of its many phases, similarities to work in other fields. However, in each phase problems are inevitably encountered which require application of principles in a manner peculiar to pipelining. The best solution of these problems requires familiarity with pipeline construction as well as thorough grounding in the general problem involved. The crossing of rivers by pipelines is no exception to this rule. The problems presented are similar in many respects to those involved in the river crossings of other types of land transportation. Nevertheless, in a good many respects the design of a pipeline crossing is unique. The author has attenpted to avoid repetitive statement of the principles and considerations which govern river crossings in general, and to confine the scope insofar as practicable to their special applications in pipeline work. However, the successful crossing of a river requires thorough study of the way rivers behave and why, and particularly how the river in question acts and will act in the future. It is, therefore, felt necessary to go into the fundamentals of river engineering at some length.

Characteristics of Rivers

The word "river" covers a large variety of streams and their characteristics vary widely. Very few general statements can be made that would be applicable to all rivers. Each river must, therefore, be considered as a separate problem. Some rivers have rocky beds; some are subject to sudden severe floods; some meander in silty plains; some have acid or alkaline water; depths may vary from 2 or 3 feet to 200 feet, and widths from 200 or

300 feet to over a mile. A study of the hydrology is necessary for the determination of rainfall, run-off and stream flow. The geology of the watershed and of the river reveals significant data concerning erosion and future action. Hydraulics, soil mechanics, and potamology are important fields of investigation in the solution of river problems. Of most use in the understanding of present regimen and the prediction of the future river activity are the gauge records and maps of previous, as well as up-to-date, surveys and previous and up-to-date cross sections and profiles for considerable distances up and downstream from the site under consideration.

Types of Crossings

There are basically two types of crossings; viz., bridges and underwater crossings. Bridges are used comparatively seldom in comparison with the other types. A great deal of study has been devoted to the design of bridges for pipelines so as to minimize the size of members and the cost of the piers. Nevertheless they are generally much more expensive, are more costly to maintain than properly built underwater lines, and are liable to damage from high winds and flying objects. They are also fully as vulnerable to damage from caving banks as underwater lines. Their economical use would therefore seem to be confined to deep gorges with stable banks. A good example of a pipeline bridge is shown on Fig. 1.

In the construction of underwater crossings several ideas about the proper layout have been followed. Crossings are sometimes made by laying the pipes across the river on top of the bed and banks but more frequently by entrenching them into the bed and banks to give them protection. When the lines are laid on the bottom without entrenchment, they are usually heavily weighted and the crossing is made by use of a number of small lines which are connected to the land line through headers. Formerly, it was commonly accepted practice to lay all lines with bows either upstream or downstream between banks. Pipes laid in this manner were sometimes placed in trenches and sometimes on the bottom without entrenchment. One company has used multiple small pipe laid in "sinusoidal" curves across the bottom of the Mississippi River at its crossings of that stream.

The advantages claimed for curves in the plan of the crossing seem to be questionable but there is no doubt as to the advantage of the greater flexibility of small pipe in conforming to bed changes provided extra length is available; to the fact that a number of smaller pipe in a crossing make complete loss of service by rupture of the pipe less likely; and that a cheaper crossing can be constructed without entrenchment. The crossing of the Mississippi River near Natchez by Interstate Natural Gas Corporation consisting of seven 10-inch lines was constructed in 1926 and only one line has been lost. It was broken by the dragging anchor of an LST boat in 1944. These lines are very heavily weighted. The river at this location is considered unusually stable; nevertheless, it has been found necessary to keep a constant watch on the crossing and to "feed" a good many feet of pipe into the river on each line to prevent breaks due to bed and bank changes even though they have been comparatively small.

The crossing of a river by straight continuation of the land line pipe without decrease in size provides obvious advantages although it is usually somewhat more expensive in first cost. In a river of the type and size of the Mississippi such a crossing must be entrenched below probable scour lines in

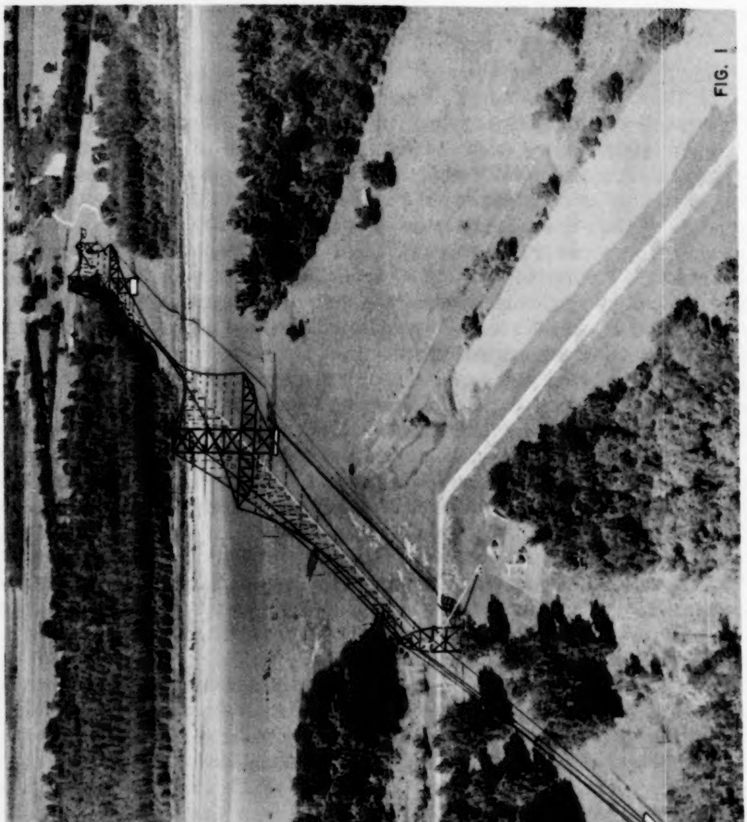


Fig. 1. United Gas Pipeline Crossing of Red River near East Point, La.

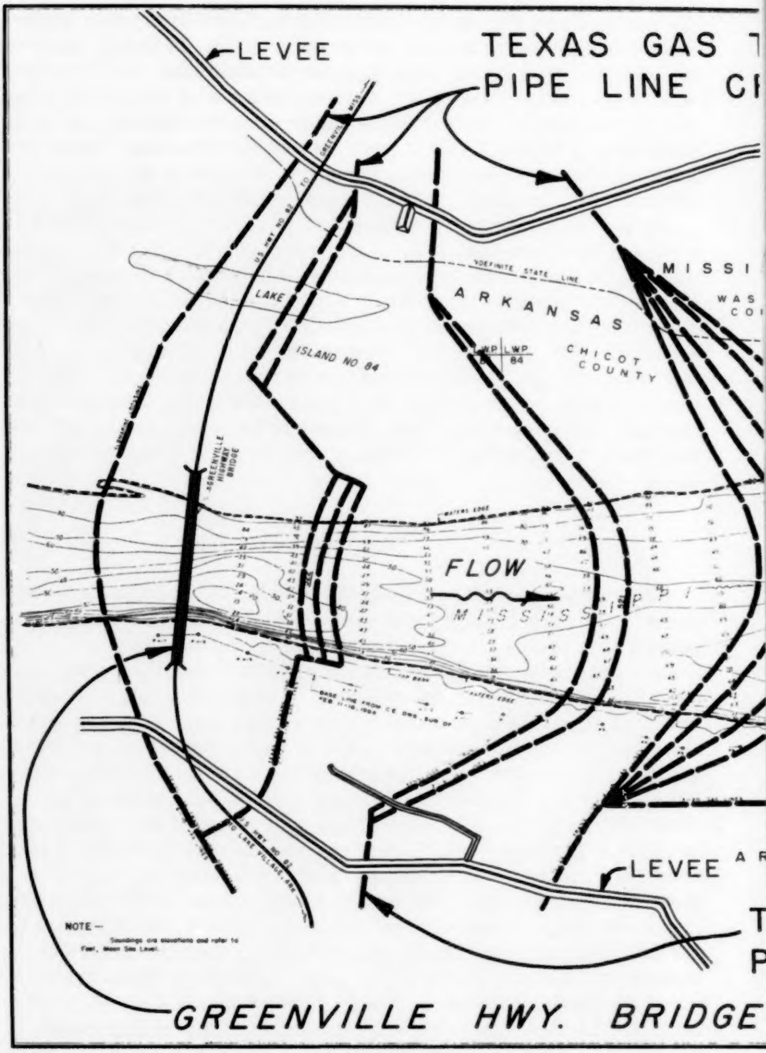
the bed and into the banks a sufficient distance to provide against exposure by caving during the economic life of the project. In large, important crossings an auxiliary line of the same size as the main line is always provided as an insurance factor. One of the main advantages of using pipe of main-line size in the crossing is that scrapers can be carried through the lines without the necessity of having traps at each side of the crossing. When the design of such a crossing is based on adequate investigation and careful consideration of the factors involved, it is fully as safe as any other type.

In making all river crossings it is of primary importance to locate them in a part of the river that is as stable as possible. The Mississippi River is notable for its meandering tendencies and stable reaches are the exception. One such is found in the vicinity of the Greenville Bridge. This reach of the river has therefore become a veritable "pipeline alley," as can be appreciated from Fig. 2. Here can be seen pipes laid straight across the river as well as pipes bowed both up and downstream. Tennessee Gas Transmission Corporation has several pipes on the bridge itself, which was bought for the purpose, it having been found cheaper to buy the existing toll highway bridge and make it free to highway traffic than to build a new bridge for pipelines only.

Selection of the Site

Rivers not only differ among themselves but the characteristics of the same river vary greatly from place to place along its length. While it is conceivably possible to construct a durable river crossing at any given location, from a practical standpoint it is necessary to exercise great care in the selection of the site for the crossing in order to be able to build it within the limits of available time and for a reasonable amount of money. The overall alignment of the pipeline must, of course, be taken into consideration in the selection of the site, but when rivers the size and character of the Mississippi are to be crossed, large changes in alignment are frequently necessary in order to avoid reaches which exhibit extreme instability. The basic problem in the selection of the site as well as in the design of the crossing of an alluvial river lies in understanding what the river is in the process of doing at the time and by study of this action and of available data to predict within relatively narrow limits what it will do within a given future period. In making the study for selection of the site it is first necessary to compile the history, geology, and hydrology of the stretch of river within which the crossing could be feasibly and economically made. Basic data is usually obtainable from the records of the Corps of Engineers, U. S. Army, and other federal and state agencies. A study of this information makes possible a fairly close approximation of the best location. It is then necessary to make an accurate up-to-date survey of the river, noting caving banks, sand bars, etc., so as to arrive at exactly the best location within the selected reach.

A map prepared for use in the selection of a pipeline crossing of the Mississippi River is shown on Fig. 3. The bank line locations in accordance with surveys made by the U. S. Mississippi River Commission in 1881-82, 1913, 1939, and 1953 are plotted for 21 miles of river. Levee lines and significant data from geological reports are also shown. Thalweg profiles for these years for this reach were also plotted on another drawing. On the basis



TEXAS GAS T
PIPE LINE C
LEVEE
LAKE
ISLAND NO 84
ARKANSAS
CHICOT COUNTY
MISSI
FLOW
MISSISSIPPI
LEVEE
GREENVILLE HIGHWAY BRIDGE
NOTE — Soundings are elevations and refer to Feet, Mean Sea Level.
GREENVILLE HWY. BRIDGE

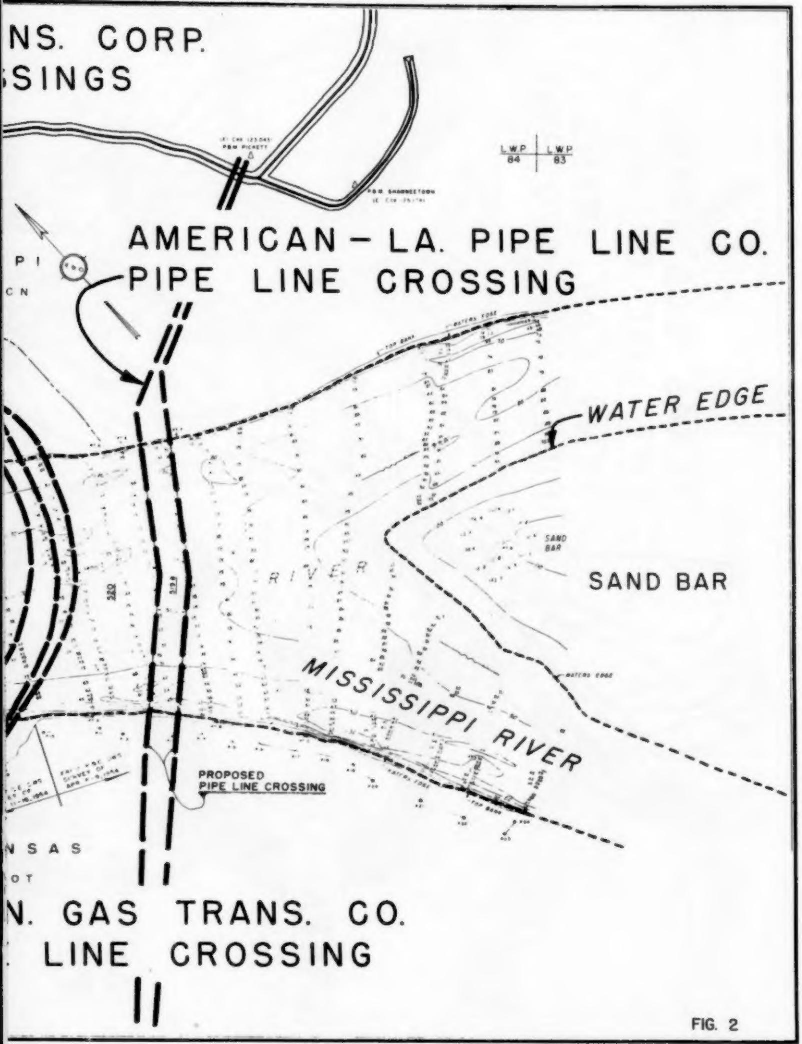
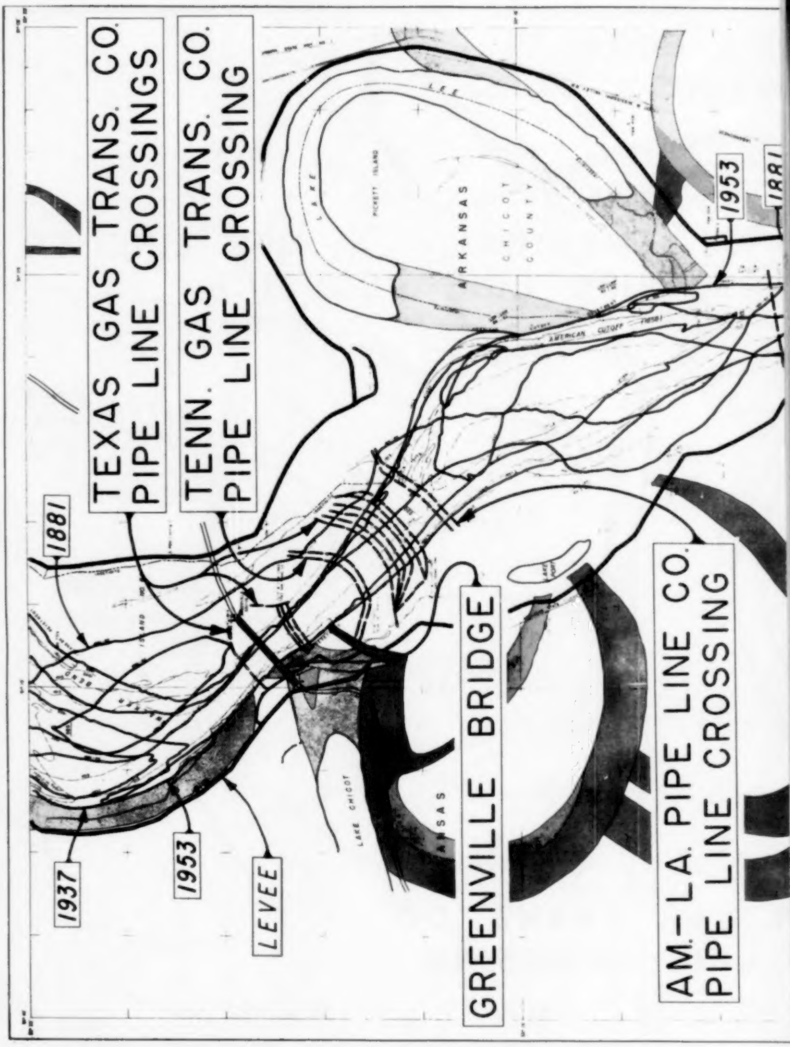
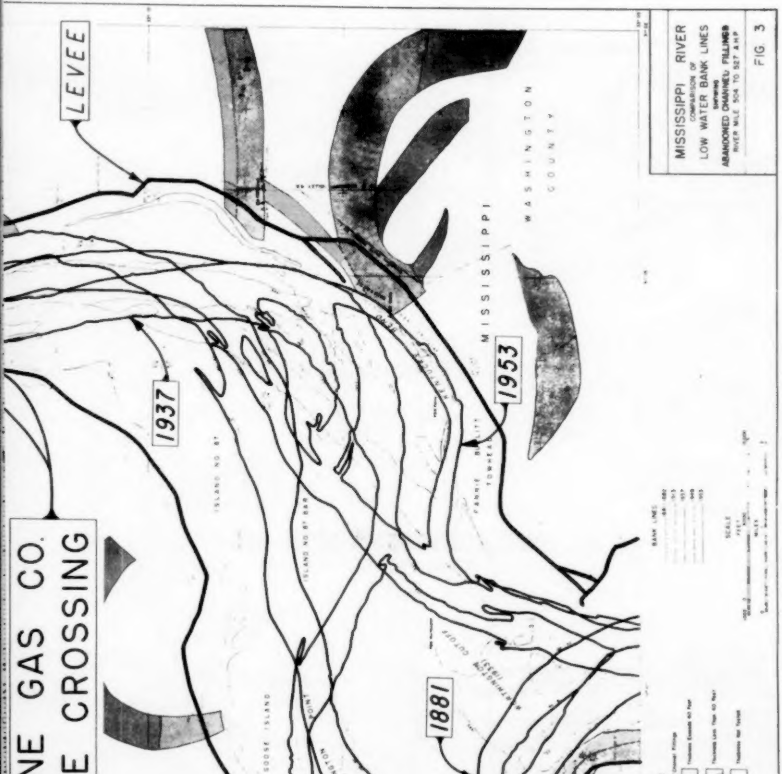
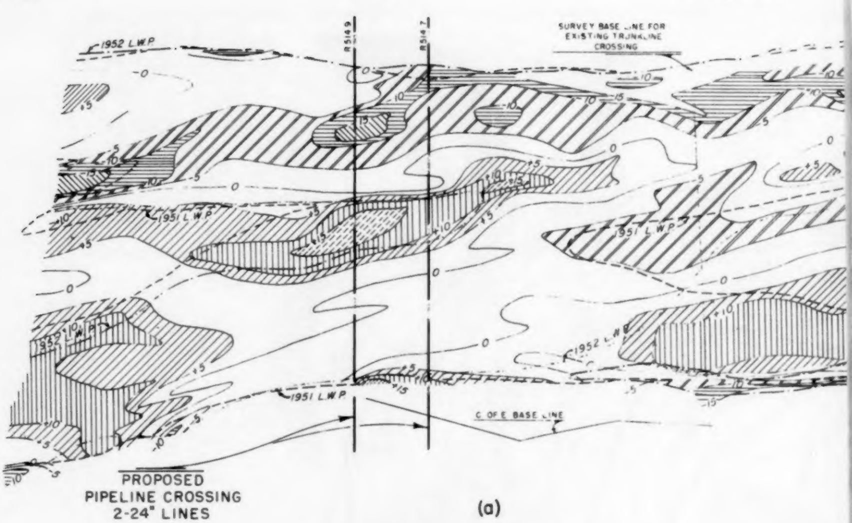

NS. CORP.
SSINGS
AMERICAN – LA. PIPE LINE CO.
PIPE LINE CROSSING
WATER EDGE
SAND BAR
RIVER
MISSISSIPPI RIVER
PROPOSED
PIPE LINE CROSSING
N. GAS TRANS. CO.
LINE CROSSING

FIG. 2


TEXAS GAS TRANS. CO.
PIPE LINE CROSSINGS
TENN. GAS TRANS. CO.
PIPE LINE CROSSING
1881
1937
1953
LEVEE
GREENVILLE BRIDGE
AM.-LA. PIPE LINE CO.
PIPE LINE CROSSING
1953
1881
ARKANSAS
CHICOT
COUNTY
PICKETT ISLAND
LAKE CHICOT

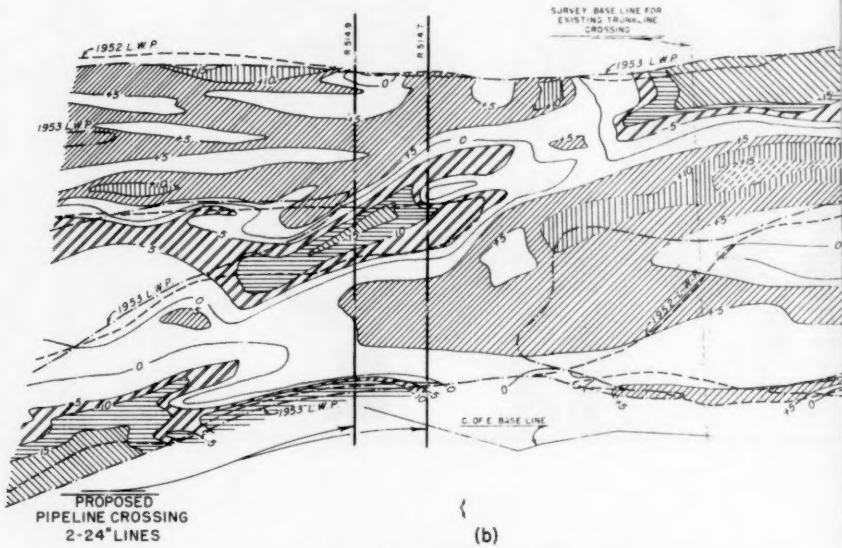

LEVEE
TRUNKLINE GAS CO.
PIPE LINE CROSSING
1937
1953
1881
CLAY PLUGS
MISSISSIPPI
WASHINGTON
COUNTY
GOOSE ISLAND
ISLAND NO 87
ISLAND NO 87 BAR
FANNIE BAYOU
BURNINGTON POINT
GRAND LAKE
MISSISSIPPI RIVER
COMPARISON OF
LOW WATER BANK LINES
SHOWING
ABANDONED CHANNEL FILLINGS
RIVER MILE 504 TO 527 AHP
FIG 3



(a)

MAR.-APR., 1951 TO APRIL, 1952

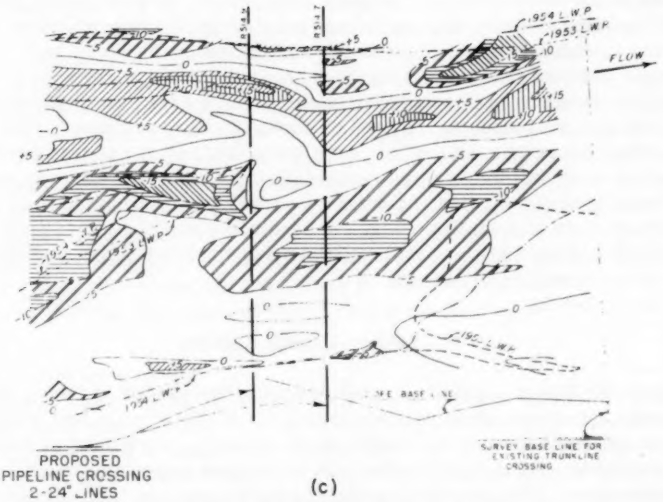
STAGE 29.0 TO STAGE 33.2



(b)

APRIL, 1952 TO APRIL, 1953

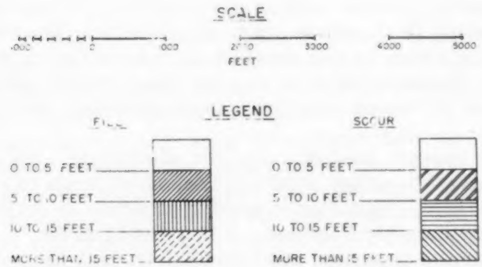
STAGE 33.2 TO STAGE 24.6



(c)

APRIL, 1953 TO FEB., 1954

STAGE 24.6 TO STAGE 8.6



NOTES

Stages shown are the mean stage during each survey & refer to the Warfield Point Gage. Bankfull at Warfield Point is 39', & the L.W.P. is 0.42'. Gage zero is 88.35' m.s.l.

Low Water Plane (L.W.P.) is 81.5' m.s.l. at Crossing Site.

Survey of Feb. 25-26, 1954, was made by P & O assisted by Trunkline Field Party. Other surveys made by U.S.C.E., Vicksburg District, on the following dates: Mar 26 - Apr 5, 1951, April 21, 1952; & April 14-22, 1953.

MISSISSIPPI RIVER

BED CHANGE MAPS

IN THE VICINITY OF THE

PROPOSED PIPELINE CROSSING

PYBURN & ODOM CONSULTING ENGINEERS

BATON ROUGE, LOUISIANA

APRIL 7, 1954

FIG. 4

of this study several locations were selected for more detailed investigation. This detailed investigation included Bed Change Studies, as shown graphically in Fig. 4, which indicate the direction of action of the river and whether the changes indicate that there may be a general trend in progress or whether the changes are more or less cyclic. Comparative cross sections were also plotted at these locations. Based on these studies, profiles for underwater crossings based on a life of 20 years were laid out at the tentatively chosen sites and cost estimates were computed. The crossing site was selected on the basis of these studies. A detailed survey was then made at the selected site to be sure that no important changes had occurred subsequent to the last available survey and to provide information for final layout and the preparation of construction drawings.

Design Considerations

In the design of a pipeline river crossing the effects of buoyancy, stream currents, stream turbulence, scour and fill of the stream bed, bank recession, debris and sand movement, temperature changes, anchoring of boats, dredging, corrosion, corrasion, and attack by marine organisms must be taken into consideration. Of these factors the characteristics of the external dynamic loads, i.e., those caused by currents and turbulence, are probably the least understood and are also the most frequent cause of trouble. Pipeline crossings of rivers, whether submerged or aerial, present basically the problem of a cylinder submerged in a moving fluid. Both aerial and submarine crossings are thus subject to several similar dynamic loads derived from the movement of the surrounding fluid. These loads differ in their magnitude and relative importance as the density and possible velocity of the surrounding fluid, i.e., air or water. Perhaps the most readily conceived of these loads is drag, or the downstream force resulting from impingement of the current, or wind, on the pipe.

The second dynamic load is a periodic alternating load acting perpendicular to the primary direction of the current which tends to induce vibration of "flutter" of the pipe. This type of load occurs only at certain combinations of stream velocity and pipe diameter. It is a result of the "circulation" about the pipe and may be examined and evaluated through the relations exposed by the "von Karman Vortex Trail."

A third load resulting from the dynamic effects of the moving fluid is that resulting from the "turbulent velocity fluctuations" of the passing flow. Less is known of the details of this phenomenon than of the two foregoing load sources. Briefly, it results from the fact that in turbulent flow the instantaneous downstream velocity at a point varies widely with time; that is, there are irregular velocity pulsations. These velocity pulsations result in a variation of total pressure at the point; and the variation in pressure between adjacent points, or between a relatively still or constant velocity fluid, such as that premeating the bed, and a point within the moving fluid, results in loads acting toward the relatively low pressure point.

Drag

The "drag" or downstream force acting on a submerged pipe may be readily estimated by means of well established experimental drag coefficients once the pipe size and design velocity of the fluid are established. A horizontal downstream force or drag load of 25 lbs. per linear foot of smooth 30-inch

pipe is produced in water at a current velocity of about 5.5 feet per second; and a force of 75 lbs. per foot of pipe is produced at a velocity of about 9 feet per second. The drag load per linear foot of 30-inch pipe suspended in a 100 m.p.h. wind would be approximately 25 lbs. per lin. ft.

The horizontal wind load effects on pipeline bridges are resisted by the wind cables. On submarine lines, it is desirable to avoid such loading either by adequate entrenchment or in some instances where small lines are involved, the provision of weight sufficient to hold the line in position on the bottom and minimize exposure. The most critical condition of drag force loading on submerged lines usually occurs during the laying or pulling operation. The possible magnitude of the drag load requires that during the construction of submerged lines full advantage be taken of the natural low velocity periods and that the line exposed during laying be provided with adequate support.

Vibratory or Flutter Loading

The periodic loads resulting from "circulation" about a cylindrical object result in the most spectacular, as well as one of the most dangerous, load conditions encountered in suspended pipelines.

Circulation is induced about a cylinder by the formation of vortices in its wake. These vortices, at certain Reynold's numbers, form and then break away on alternate sides of the cylinder's wake. The characteristic wake developed by vortices spaced regularly and alternately behind the cylinder is called the "von Karman Vortex Trail."

On a rigid cylinder the period of vortex formation and shedding, and thus the period of force reversals, is dependent on the velocity of the flow. If the cylinder is free to vibrate the proportionality between stream velocity and vortex shedding is obscured by a tendency toward the development of vortices in phase with the natural frequency of the cylinder and its supporting structure. The most severe vibration and oscillation occurs under this combination of forced vibrations resulting from vortex formation and "self-excited" vibration at the natural period of the suspended cylinder.

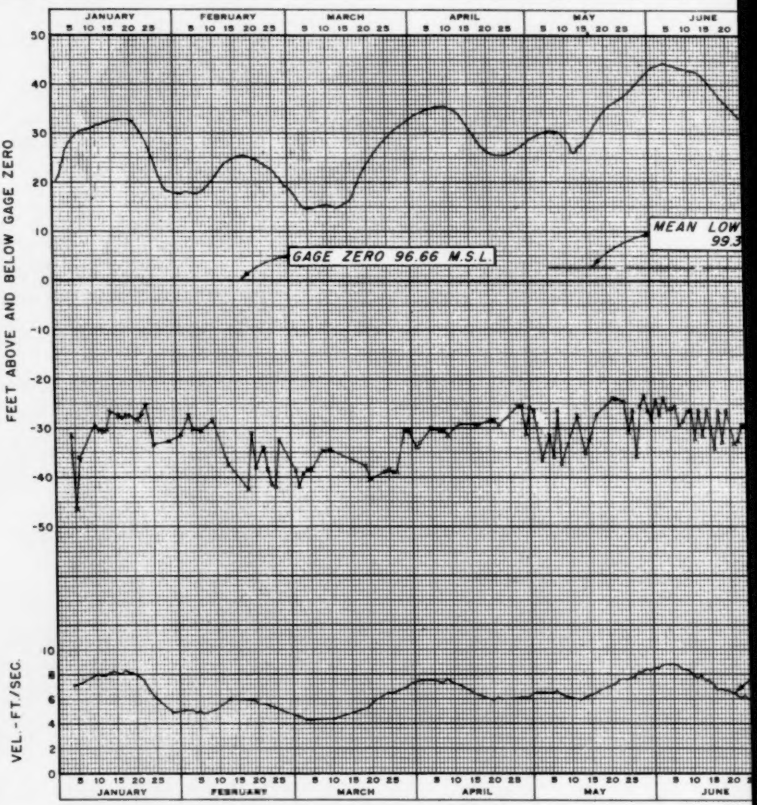
Examples of the deflection and stress conditions that may be expected as the result of such loading is afforded by the observed oscillation of pipeline suspension bridges, the "singing" of telegraph wires, and the "flutter" of pipes suspended in water.

Remedial action for the prevention of such oscillations include such measures as increasing the stiffness of the structure, and thus changing its natural period, the installation of damping devices, or, in some instances, the alteration of the structure profile by the installation of shrouds or similar devices. With submerged pipelines, the best solution is again adequate cover with the hope that the most critical conditions will occur during laying.

Turbulence Loading

Loads resulting from turbulent velocity fluctuations are irregular, and are generally obscured by the previously discussed more readily analyzed loads. They are of particular significance during the initial stages of submarine pipeline exposure, as the line is uncovered by scour. Their possible magnitude requires that they be given consideration.

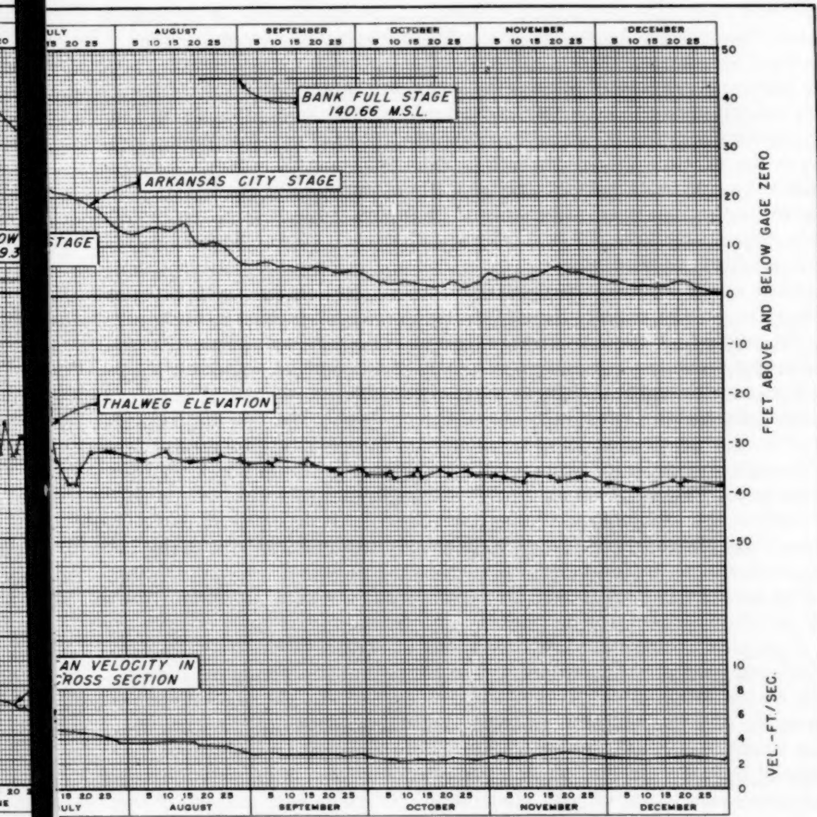
Present knowledge does not permit an estimate of the areal extent over which such pressure differences may obtain. It is of interest to note in this connection, however, that such pressure variations have been held responsible for the "lifting" of articulated concrete mat revetments.



NOTES:

The discharge range is located about 7 Miles above Arkansas City, Arkansas at Chicot Landing Approximate Mile 558.9.

Data obtained from Results of Discharge Observations, U.S. Engineer Office, Vicksburg, Mississippi.



MISSISSIPPI RIVER

1943

STAGE & BOTTOM VARIATIONS
AT CHICOT LANDING DISCHARGE RANGE

PYBURN & ODOM CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA

APRIL 1954 FILE NO. 33-102-09

FIG. 5

Design against pressure variations resulting from turbulence is generally adequately provided for by the measures outlined above for resistance to drag and flutter forces.

The only practical method of protecting a large line against most of the dangers referred to above lies in entrenchment into the bed and banks of the river. For streams flowing in channels composed of hard rock a trench is blasted across the stream deep enough to permit covering the pipe. This trench should have a smooth bottom and be laid out so that the pipe can be fitted to it with as few bends as practicable. It is desirable to pad the trench with sand and gravel and to backfill it with small broken stone since no natural filling can usually be expected.

Entrenchment in alluvial rivers requires a great deal more consideration. Bank and bed changes are constantly occurring in such streams to more or less extent. In order to insure an underwater pipeline against damage from currents, dragging anchors, corrasion, etc., the pipe must be entrenched into the bed and banks sufficiently that bank movement will not disturb it nor scour uncover it during the economic life of the project. The accomplishment of this objective may be limited in some cases by the availability of capable equipment although hydraulic dredges with digging depths of as much as 100 feet are in service. The decision as to the entrenchment into the bottom is based on a study of the available cross sections and thalweg profiles and a consideration of the phenomenon of cyclic variation in the elevation of the bed which varies with stage. In the most stable reaches of an alluvial river neglect of this last factor has been known to result in failure of a pipeline. There are very few locations where the amount of this variation has been accurately measured. A graph showing the variation in the elevation of the thalweg during a period of one year plotted against gauge heights at an otherwise stable cross section on the Mississippi River is shown on Fig. 5. Entrenchment into the banks as well as the decision as to the maximum depth of the pipe in the stream is based to a considerable extent on the comparative study of the cross sections at the site for the various years of record. Bank entrenchment also must be based on a study of past changes in the horizontal pattern of the river. A reach that is stable today may be found to be in imminent danger of becoming unstable because of changes which are occurring above or below the site. There are few, if any, places on the Mississippi above Baton Rouge where bank changes cannot be expected to occur more or less rapidly. The decision as to amount of bank entrenchment must be based on an estimate of what the rate of change will be in the future and how long the project is expected to last.

The best method for entrenching the pipe across a large alluvial stream is by means of hydraulic dredging in the bed and in the banks up to the water surface, the trench to be excavated prior to the placing of the pipe. It is not usually necessary to fill the trenches between banks since the river will take care of that in short order. The bank trenches should be backfilled to restore the original alinement of the bank line if it is practicable to do so. This backfill should be protected by riprap or sandbags and the top of bank shaped so as not to permit drainage to run over the new fill.

The steel from which the underwater pipeline is made should have as much flexibility as is consistent with strength and weldability requirements. For land lines it has become the practice to raise the yield point by expansion of the pipe so as to lower the required wall thickness. Underwater crossings are more inaccessible and a break in such a crossing is many times as

expensive to repair as a line on land. It is, therefore, very important to specify carefully the steel to be used with regard to ductility as well as strength. Working stresses should be lower than those normally used in land pipe. Sagbends and overbends, if required, should be bent on the job to fit the trench as actually dug. In many cases it will be found feasible to lay the pipe without pre-bent bends which is of considerable advantage from the standpoint of laying.

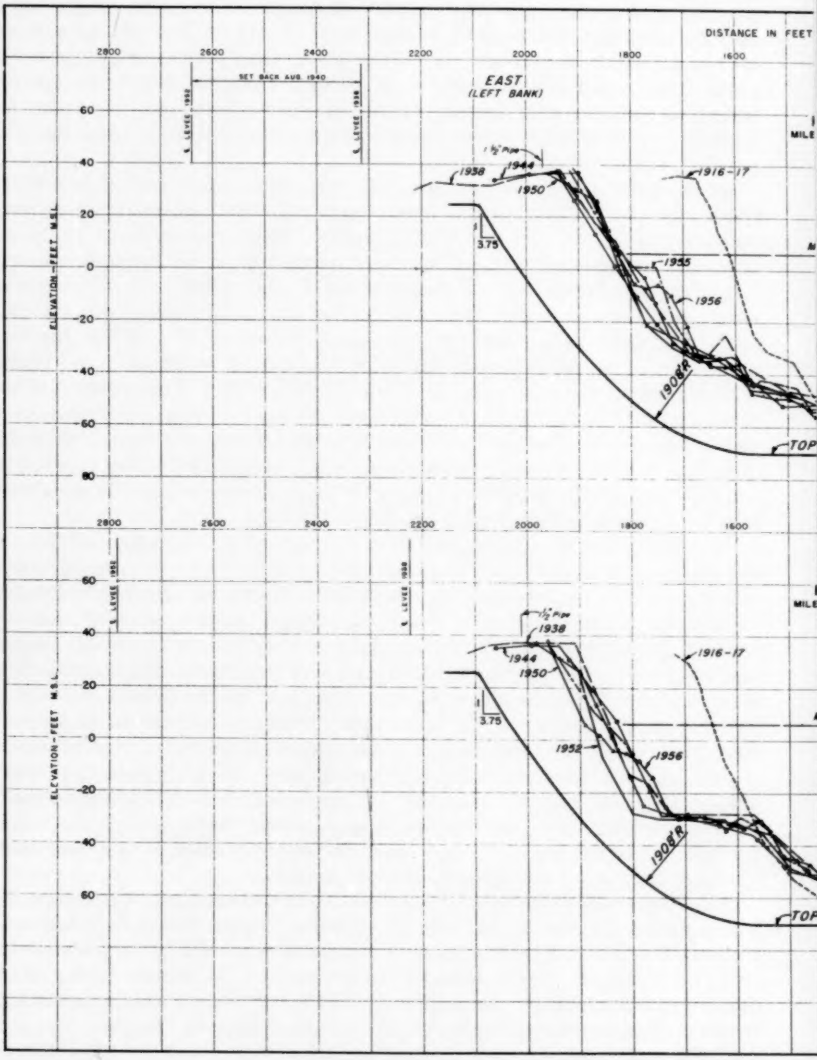
In the design of large pipelines the wall thickness required to take care of the pressure always provides less weight than that necessary to overcome the buoyancy of the empty pipe. This buoyancy must be overcome by the addition of weight to the line. Weight in excess of that required for overcoming the buoyancy as computed on the basis of its displacement of fresh water must be added so as to cause the pipe to settle into the trench at the desired location even if it is partially filled with soft silt. It has been found that for large pipes across the Mississippi River the addition of weight so as to furnish a total weight in air equivalent to about 1.3 times that of the volume of water displaced by the pipe plus the weighting material is sufficient for good placing and to insure that the pipe will remain in place until the trench is backfilled. Small pipes are frequently laid directly on the bottom without trenching because of the relative expense involved. Such lines are usually weighted very heavily so as to resist movement due to currents.

Weighting can be accomplished by increasing the thickness of the pipe; by the attachment of concrete or steel weights (called clamps); or by continuous coatings. The requirement for retention of maximum flexibility should be considered in the choice of a weighting method and material. It is also important, particularly during the laying process, that the area and length of pipe exposed to the current be as small and as smooth as possible. Each method of weighting still has its advocates but the continuous coating, using heavy-aggregate concrete for the coating material, is now much the most commonly used. The use of barite aggregate has been found to provide a strong, durable concrete weighing consistently 185-190 pounds per cubic foot. The coating methods are such that the surface is left relatively smooth and the coating adheres to the pipe quite tenaciously, serving to protect the corrosion coating during handling. As of the present time, it also provides the cheapest method of securing additional weight.

Fig. 6 shows design profiles for the main and auxiliary crossings of a 30-inch pipeline across the Atchafalaya River. The profile is well below the bottom elevations of the cross sections made from all of the surveys that could be obtained. The sagbend radii are such as to permit laying of the pipeline without stressing it in excess of 20,000 lbs./sq. in. in a longitudinal direction. The overbends were made cold and coated on the job. The pipe used was .656 wall thickness and the coating consisted of 2-1/2-inch thickness of 190-lb. concrete with wire mesh reinforcement.

Construction

Pipeline river crossings are usually placed either by pulling the pipe across the river after it has been welded-up on shore or by placing it from a laying barge. The laying barge method is usually slower but is preferred on large rivers particularly where there is considerable current. Whether the pipe is placed by use of a laying barge or is pulled, it must be supported


DISTANCE IN FEET
2800
2600
2400
2200
2000
1800
1600
SET BACK AUG 1940
EAST
(LEFT BANK)
ELEVATION-FEET M.S.L.
60
40
20
0
-20
-40
-60
80
1938
1944
1950
1955
1956
1916-17
3.75
1908'R
TOP
MILE
1952
ELEVATION-FEET M.S.L.

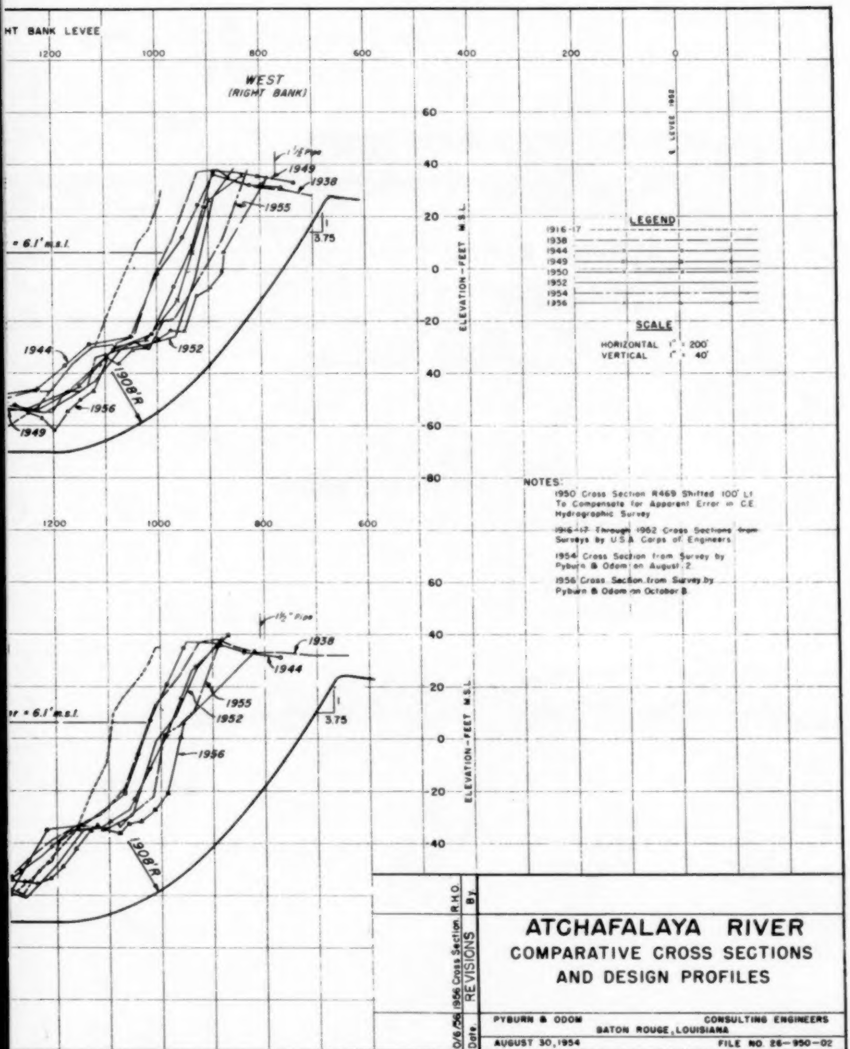
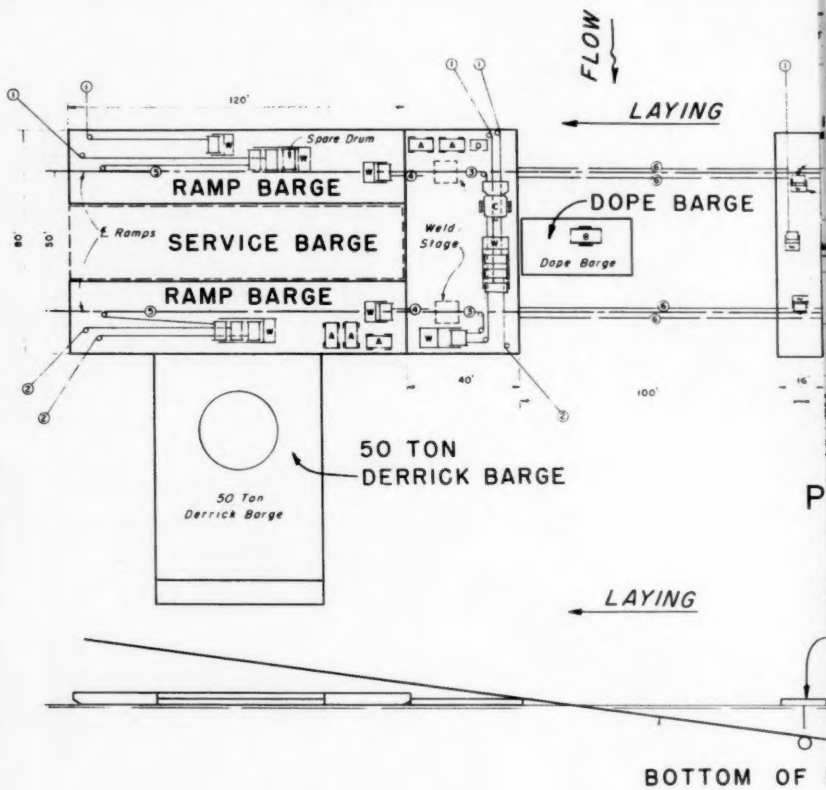
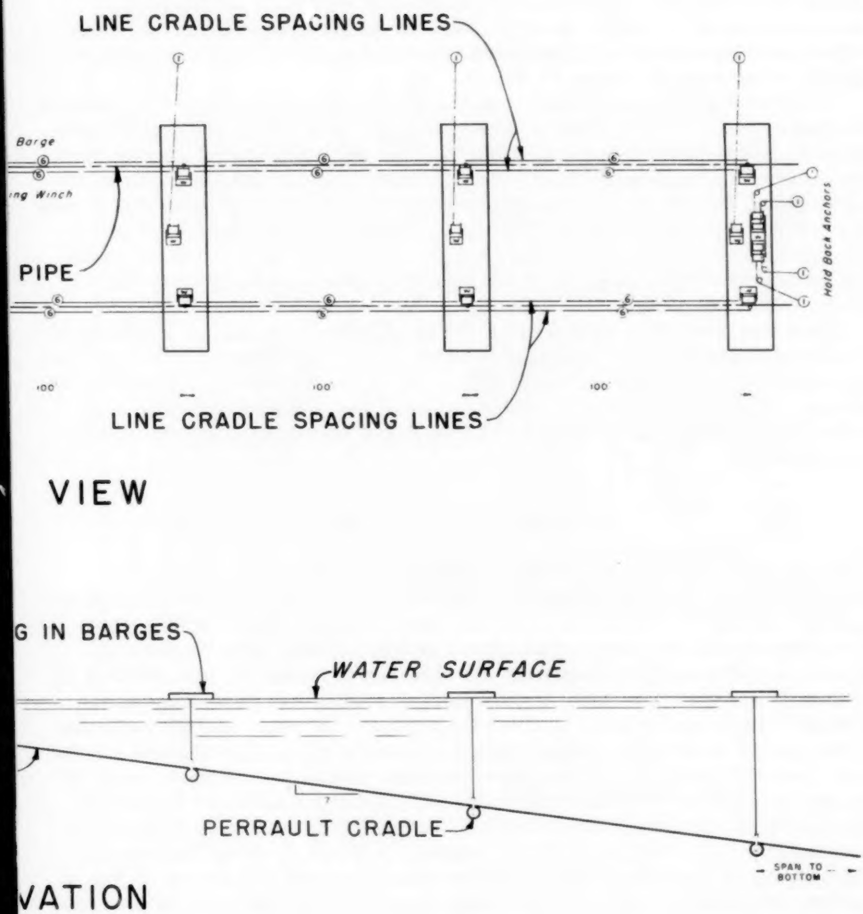

HT BANK LEVEE
WEST
(RIGHT BANK)
ELEVATION-FEET M.S.L.
LEGEND
1916-17
1938
1944
1949
1950
1952
1954
1956
SCALE
HORIZONTAL 1" = 200'
VERTICAL 1" = 40'
NOTES:
1950 Cross Section R469 Shifted 100' Lt To Compensate for Apparent Error in C.E. Hydrographic Survey
1916-17 Through 1952 Cross Sections from Surveys by U.S.A. Corps of Engineers
1954 Cross Section from Survey by Pyburn & Odom on August 2
1956 Cross Section from Survey by Pyburn & Odom on October 8
1908'R
3.75
ATCHAFALAYA RIVER
COMPARATIVE CROSS SECTIONS
AND DESIGN PROFILES
PYBURN & ODOM CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA
AUGUST 30, 1954
FILE NO. 26-950-02
10/6/56 1956 Cross Section R.H.O.
Date REVISIONS By

FIG. 6


FLOW
LAYING
120'
Spare Drum
RAMP BARGE
SERVICE BARGE
RAMP BARGE
℄ Ramps
Weld Stage
DOPE BARGE
Dope Barge
80'
30'
40'
100'
16'
50 TON
DERRICK BARGE
50 Ton
Derrick Barge
P
LAYING
BOTTOM OF



SCHEMATIC DIAGRAM
PIPE LAYING PLANT LAYOUT

FIG. 7

during the installation process so as to prevent excessive longitudinal stresses from developing. A sketch showing a typical pipeline laying barge with pipe being supported by pontoons between the end of the barge and the bottom of the river is shown on Fig. 7.

In order to get a good installation of a pipe across a large river, it is very necessary that the contractor be experienced on river work and that he have adequate and proper equipment. Construction contracts are usually let to the low bidder on a lump sum basis. The specifications are framed so as to ensure against damage to the pipe during construction and to provide that a good bed and backfill are provided. The actual details of construction are left to the contractor. This practice has resulted in permitting the owners to take full advantage of the ingenuity of contractors in devising more economical methods of construction.

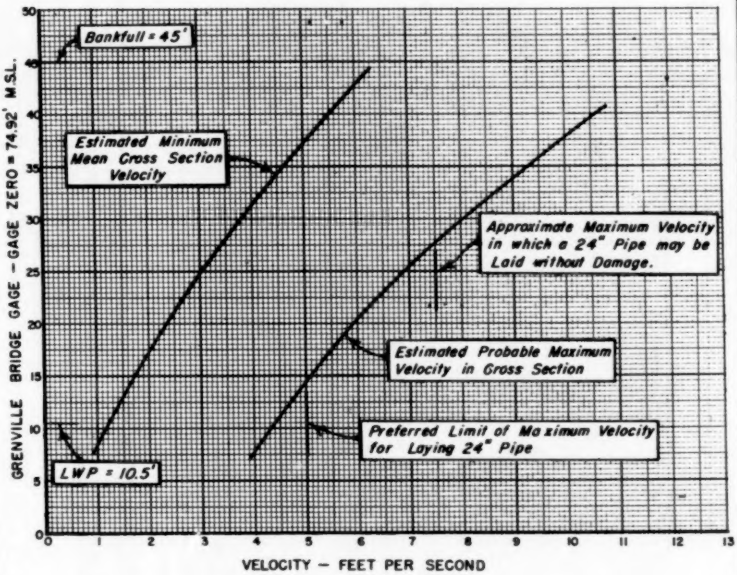
Corrosion protection is accomplished by doping and wrapping and cathodic protection similar to that provided on land lines. It is necessary to exercise extreme care in corrosion control of a crossing because of its future inaccessibility. A careful check of the chemical qualities of the river water at all stages should be made so as to determine if any special precautions will be necessary.

Selection of Working Season

On all rivers there are certain months in the year during which it is feasible to work and others when the best efforts are likely to fail. There are very few rivers for which it can be guaranteed that a trench can be opened up and a pipe can be laid every year. Some years, unpredictable flash floods will occur which will halt dredging, fill trenches or break the pipe while it is being laid. On the other hand, a great deal of misery can be avoided by the study of the hydrographs of the river for a number of years and the selection of that period of the year during which the chances of successful work are the best. The critical point in dredging of trenches is reached when the velocity becomes such that it begins to move the bed load of the stream. This point can usually be estimated fairly closely. Velocities in the Lower Mississippi River bear a close relation to gauge heights. A graph showing the relationship between velocities and gauge heights near Greenville is shown on Fig. 8. A graph prepared for a site on the Mississippi River on the basis of recorded gauge heights for a number of years from which the gauge heights to be expected during the various months of an average year can be computed is shown on Fig. 9. A horizontal line is drawn on the chart at the gauge height at which the velocity would be sufficient to cause the pipe to flutter during the laying process.

Inspection and Testing

The best laid plans of engineers are worthless unless they are followed out. The only way to ensure compliance with specifications is to inspect the work carefully during construction and to test it when it is completed. The construction of a dependable river crossing requires that the welding and corrosion inspection should be of a very high order. It is also necessary to inspect carefully dredging of the trench to proper grade and alignment. The



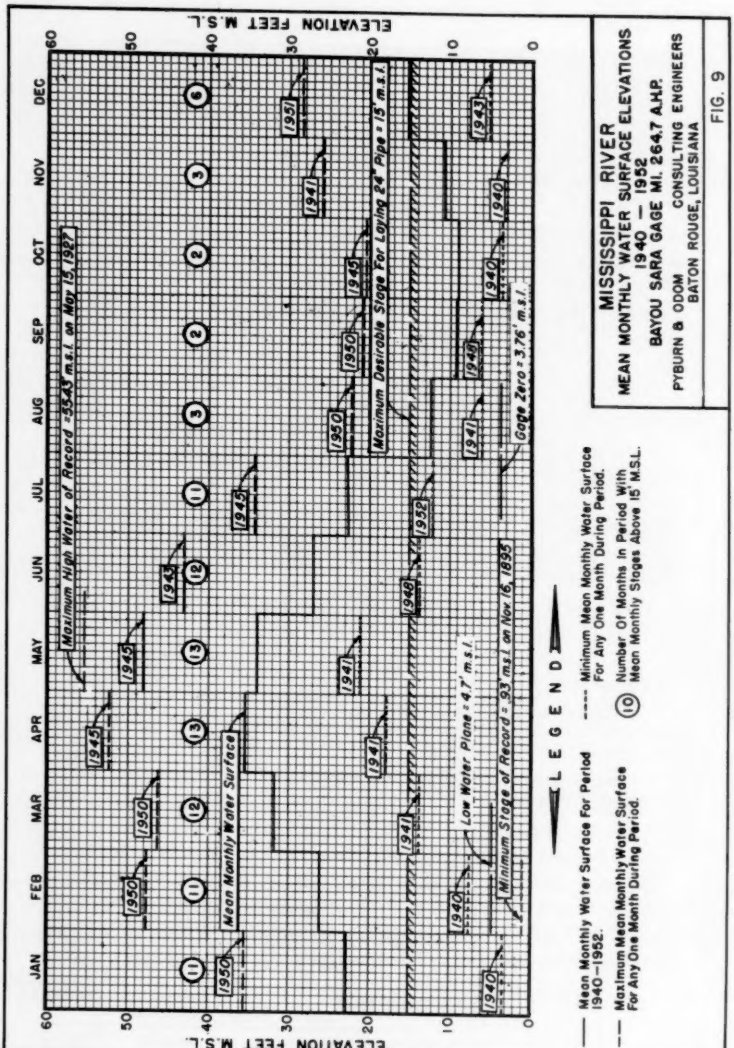
NOTES

These curves are based on similar curves (observed) for Chicot Landing & Vicksburg Discharge Ranges, adjusted for slope & cross section elements. These curves are approximate.

No allowance made for direct effect of contraction at Greenville Bridge, Mi. 522.4 A.H.P.

MISSISSIPPI RIVER ESTIMATED STAGE – VELOCITY RELATIONS VICINITY OF MILE 519.75 A.H.P.	
PYBURN & ODOM BATON ROUGE, LOUISIANA	CONSULTING ENGINEERS
MARCH 13, 1954	FILE NO. 10-400-04

FIG. 8


MISSISSIPPI RIVER
MEAN MONTHLY WATER SURFACE ELEVATIONS
1940 — 1952
BAYOU SARA GAGE MI. 264.7 A.H.P.
PYBURN & ODOM CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA
ELEVATION FEET M.S.L.
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
Maximum High Water of Record = 55.43' m.s.l. on May 15, 1927
Mean Monthly Water Surface
Maximum Desirable Stage For Laying 24" Pipe = 15' m.s.l.
Low Water Plane = 4.7' m.s.l.
Minimum Stage of Record = .93' m.s.l. on Nov 16, 1895
Gage Zero = 3.76' m.s.l.
LEGEND
Mean Monthly Water Surface For Period 1940–1952.
Maximum Mean Monthly Water Surface For Any One Month During Period.
Minimum Mean Monthly Water Surface For Any One Month During Period.
Number Of Months In Period With Mean Monthly Stages Above 15' M.S.L.
FIG. 9

pipe laying operation should be checked continually during the progress of the work.

In the surveying and inspection work of construction of trenches and keeping up with the location of the pipe while it is being laid, the author's firm has found the use of an electronic sounding device to be indispensable.

Pressure testing of the underwater line is usually more rigid than for land lines. The usual practice is to test the joints separately at pressures in excess of working pressure before welding them into the line. After the line is laid, it is customary to run a pig through and to give the crossing a test for several hours at about 125% of working pressure before backfilling. The testing is done either with gas, air, or water.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1113 is identified as 1113 (HY6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1956.

VOLUME 82 (1956)

JUNE: 990(PO3), 991(PO3), 992(PO3), 993(PO3), 994(PO3), 995(PO3), 996(PO3), 997(PO3), 998 (SA3), 999(SA3), 1000(SA3), 1001(SA3), 1002(SA3), 1003(SA3)[c], 1004(HY3), 1005(HY3), 1006 (HY3), 1007(HY3), 1008 (HY3), 1009 (HY3), 1010 (HY3)[c], 1011 (PO3)[c], 1012 (SA3), 1013 (SA3), 1014(SA3), 1015(HY3), 1016(SA3), 1017(PO3), 1018(PO3).

JULY: 1019(ST4), 1020(ST4), 1021(ST4), 1022(ST4), 1023 (ST4), 1024(ST4)[c], 1025(SM3), 1026 (SM3), 1027(SM3), 1028(SM3)[c], 1029(EM3), 1030(EM3), 1031(EM3), 1032(EM3), 1033(EM3)[c].

AUGUST: 1034(HY4), 1035(HY4), 1036(HY4), 1037(HY4), 1038(HY4), 1039(HY4), 1040(HY4), 1041(HY4)[c], 1042(PO4), 1043(PO4), 1044(PO4), 1045(PO4), 1046(PO4)[c], 1047(SA4), 1048 (SA4)[c], 1049(SA4), 1050(SA4), 1051(SA4), 1052(HY4), 1053(SA4).

SEPTEMBER: 1054(ST5), 1055(ST5), 1056(ST5), 1057(ST5), 1058(ST5), 1059(WW4), 1060(WW4), 1061(WW4), 1062(WW4), 1063(WW4), 1064(SU2), 1065(SU2), 1066(SU2)[c], 1067(ST5)[c], 1068 (WW4)[c], 1069(WW4).

OCTOBER: 1070(EM4), 1071(EM4), 1072(EM4), 1073(EM4), 1074(HW3), 1075(HW3), 1076(HW3), 1077(HY5), 1078(SA5), 1079(SM4), 1080(SM4), 1081(SM4), 1082(HY5), 1083(SA5), 1084(SA5), 1085(SA5), 1086(PO5), 1087(SA5), 1088(SA5), 1089(SA5), 1090(HW3), 1091(EM4)[c], 1092 (HY5)[c], 1093(HW3)[c], 1094(PO5)[c], 1095(SM4)[c].

NOVEMBER: 1096(ST6), 1097(ST6), 1098(ST6), 1099(ST6), 1100(ST6), 1101(ST6), 1102(IR3), 1103 (IR3), 1104(IR3), 1105(IR3), 1106(ST6), 1107(ST6), 1108(ST6), 1109(AT3), 1110(AT3)[c], 1111(IR3)[c]; 1112(ST6)[c].

DECEMBER: 1113(HY6), 1114(HY6), 1115(SA6), 1116(SA6), 1117(SU3), 1118(SU3), 1119(WW5), 1120(WW5), 1121(WW5), 1122(WW5), 1123(WW5), 1124(WW5)[c], 1125(BD1)[c], 1126(SA6), 1127 (SA6), 1128(WW5), 1129(SA6)[c], 1130(PO6)[c], 1131(HY6)[c], 1132(PO6), 1133(PO6), 1134(PO6), 1135(BD1).

VOLUME 83 (1957)

JANUARY: 1136(CP1), 1137(CP1), 1138(EM1), 1139(EM1), 1140(EM1), 1141(EM1), 1142(SM1), 1143(SM1), 1144(SM1), 1145(SM1), 1146(ST1), 1147(ST1), 1148(ST1), 1149(ST1), 1150(ST1), 1151(ST1), 1152(CP1)[c], 1153(HW1), 1154(EM1)[c], 1155(SM1)[c], 1156(ST1)[c], 1157(EM1), 1158 (EM1), 1159(SM1), 1160(SM1), 1161(SM1).

FEBRUARY: 1162(HY1), 1163(HY1), 1164(HY1), 1165(HY1), 1166(HY1), 1167(HY1), 1168(SA1), 1169(SA1), 1170(SA1), 1171(SA1), 1172(SA1), 1173(SA1), 1174(SA1), 1175(SA1), 1176(SA1), 1177(HY1)[c], 1178(SA1), 1179(SA1), 1180(SA1), 1181(SA1), 1182(PO1), 1183(PO1), 1184(PO1), 1185(PO1)[c].

MARCH: 1186(ST2), 1187(ST2), 1188(ST2), 1189(ST2), 1190(ST2), 1191(ST2), 1192(ST2)[c], 1193 (PL1), 1194(PL1), 1195(PL1).

APRIL: 1196(EM2), 1197(HY2), 1198(HY2), 1199(HY2), 1200(HY2), 1201(HY2), 1202(HY2), 1203 (SA2), 1204(SM2), 1205(SM2), 1206(SM2), 1207(SM2), 1208(WW1), 1209(WW1), 1210(WW1), 1211(WW1), 1212(EM2), 1213(EM2), 1214(EM2), 1215(PO2), 1216(PO2), 1217(PO2), 1218 (SA2), 1219(SA2), 1220(SA2), 1221(SA2), 1222(SA2), 1223(SA2), 1224(SA2), 1225(PO)[c], 1226 (WW1)[c], 1227(SA2)[c], 1228(SM2)[c], 1229(EM2)[c], 1230(HY2)[c].

MAY: 1231(ST3), 1232(ST3), 1233(ST3), 1234(ST3), 1235(IR1), 1236(IR1), 1237(WW2), 1238(WW2), 1239(WW2), 1240(WW2), 1241(WW2), 1242(WW2), 1243(WW2), 1244(HW1), 1245(HW1), 1246 (HW1), 1247(HW1), 1248(WW2), 1249(HW1), 1250(HW1), 1251(WW2), 1252(WW2), 1253(IR1), 1254(ST3), 1255(ST3), 1256(HW1), 1257(IR1)[c], 1258(HW1)[c], 1259(ST3)[c].

JUNE: 1260(HY3), 1261(HY3), 1262(HY3), 1263(HY3), 1264(HY3), 1265(HY3), 1266(HY3), 1267 (PO3), 1268(PO3), 1269(SA3), 1270(SA3), 1271(SA3), 1272(SA3), 1273(SA3), 1274(SA3), 1275 (SA3), 1276(SA3), 1277(HY3), 1278(HY3), 1279(PL2), 1280(PL2), 1281(PL2), 1282(SA3), 1283 (HY3)[c], 1284(PO3), 1285(PO3), 1286(PO3), 1287(PO3)[c], 1288(SA3)[c].

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c. Discussion of several papers, grouped by Divisions.

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